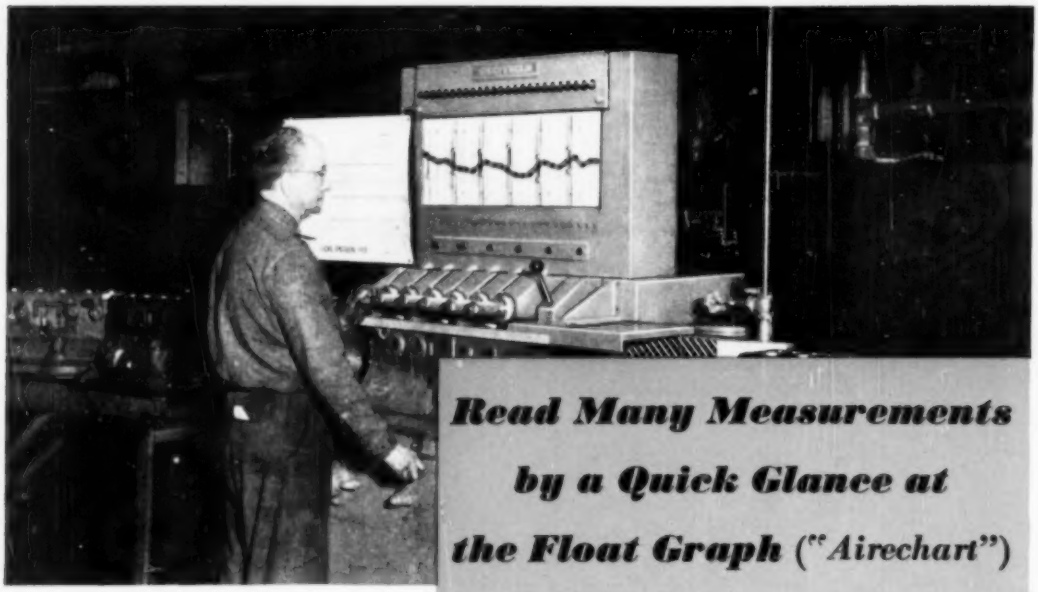
Industrial QUALITY CONTROL

JANUARY, 1952

VOL. VIII, NO. 4

A Control Chart in a Telephone Order Office

AMERICAN SOCIETY FOR QUALITY CONTROL



Checking bore diameters at 18 points.

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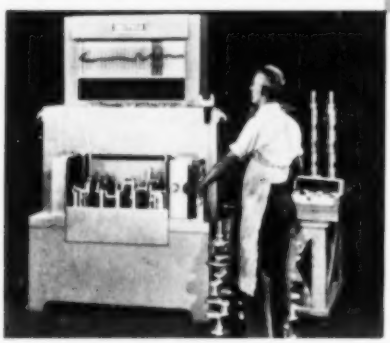
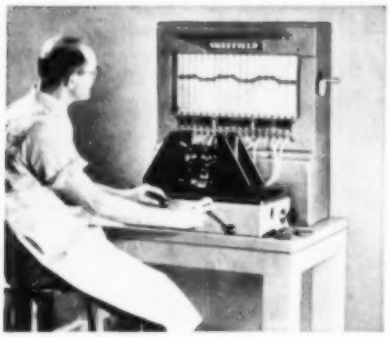


Checking 27 crankshaft measurements.



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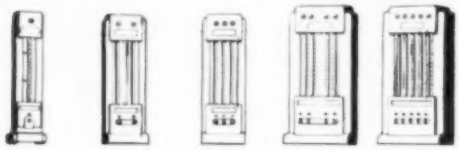

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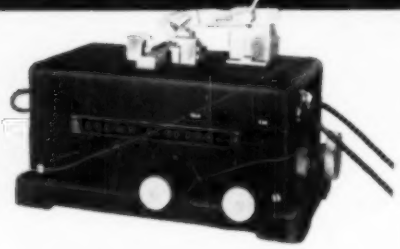

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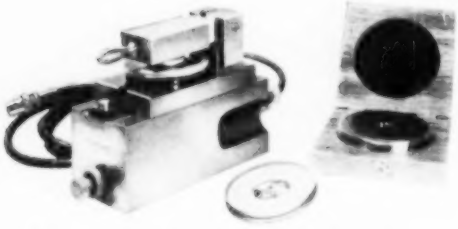

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AL DAVIS APPOINTED TO NEW POST AT RIT

Alfred L. Davis, our genial Executive Secretary, has been named Director of Public Relations at Rochester Institute of Technology.

Al, who took over the newly created post on October 1, 1951, was Associate Director of the Institute's Evening and Extension Division since 1945. He joined the Institute staff as an instructor in 1938 after earning a Master's Degree in social science at Syracuse University. He is a graduate of Salem College in Salem, W. Va.

In 1941, Davis left RIT to become Chief Inspector of the Mechanical Parts Division at Bausch & Lomb Optical Company, where he organized a training program in quality control. He served as the first President of the Rochester Society for Quality Control and was one of the founders of ASQC. He rejoined the RIT staff in 1945.

The Society offers hearty congratulations to Al on this well deserved recognition.

INSTRUMENT GAGING IN SQC

It is axiomatic that effective control charts must depend on good data. Good data come only from reliable inspection techniques, and these, in turn, require having instruments that can do the job. Thus, there must always be an intimate relation between adequate inspection equipment and competent statistical quality control.

This theme is developed in an interesting, 20-page pamphlet entitled "Instrument Gaging in Statistical Quality Control" available on request from the Sheffield Corporation, Dayton 4, Ohio. Some 14 case histories are pictorially presented with brief descriptive comments.

Visitors at the Sheffield exhibit during the ASQC Convention in Cleveland were invited to take home copies of this booklet. Additional copies are now available without charge to readers of IQC.

COVER PICTURE

We are indebted to Alden's, Inc. for this picture which shows a typical control chart used in one of their several catalog order offices for helping maintain accuracy on customer orders taken by telephone.

As can be seen, the chart is prominently displayed near the activity where the work is being controlled.

Industrial Quality Control

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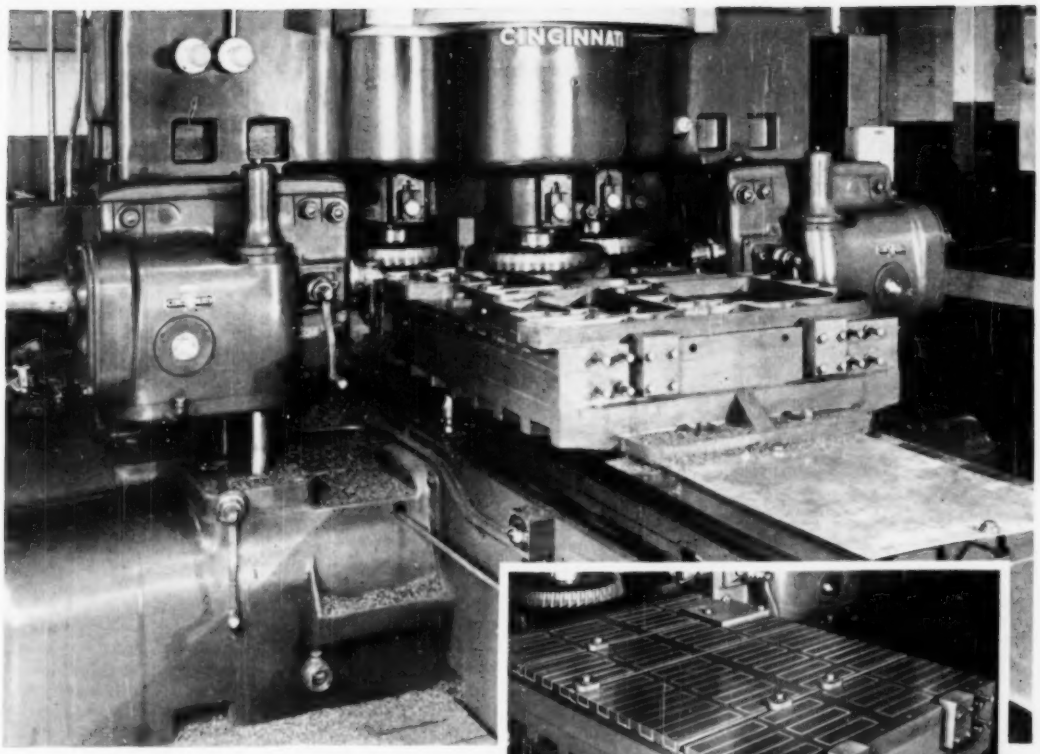

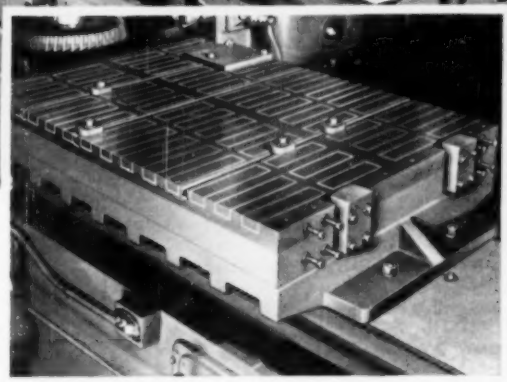

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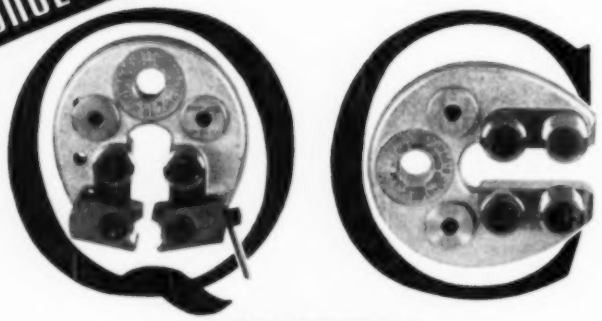

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Statistical Methods in Chemical Development*

CHARLES A. BICKING

Research and Development Division—Office, Chief of Ordnance**

THERE are many advantages in the use of statistical methods in research and development. Some of the most important advantages are given in Table 1.

TABLE 1—**Some Advantages of Statistical Methods in Research and Development**

1—Reduction of experimental work to a minimum without sacrifice of essential information.
2—More reliable conclusions because experimental error has been measured and reduced to a minimum.
3—Faster progress in profitable directions because interpretations given to experimental data have been improved.
4—Presentation of the evidence in most convincing form.

The first two advantages arise from a carry-over to industry of the work of mathematical statisticians in agricultural, biological, and social science problems. With a little imagination, industrial experimenters may carry over into their own planning, the principles developed by experimenters[1] in those other sciences. Many research workers with little or no formal statistical training are designing experiments more successfully than before with the help of the growing number of usable texts on the subject.

However, the last two advantages listed have not been so fully enjoyed for a two-fold reason. Most mathematical statisticians are lacking in knowledge of the technical background involved in industry. On the other hand, few research workers have gone as deeply into the study of statistical theory as is necessary to reap its greatest advantages. On the one hand, the text book writers rarely carry their explanations beyond the stage of determining statistical significance. At the same time, the technical workers, perhaps because of a fundamental deficiency in training, have difficulty translating the statistical evidence to technical and economic equivalents.

This dilemma has given rise to a new specialist whose duties parallel those of the quality control engineer who works in the production phases of industry. This specialist, who may be called a "research engineer", or some more appropriate name, is usually a technical man turned statistician. He is a member of the research and development team with a breadth of approach and a degree of responsibility which makes him an efficient coordinator of research. He interprets the language and the method of mathematical science in terms of technical realities. He then transmits the technical evidence in the economic terms which are understood by management. Although this work has something of a pioneering nature, when capable performance and convincing presentation of results are brought to bear on lower development costs and on more certain and faster results, there can be little doubt of the position it will hold in the future. Competent performance of the job provides a natural stepping stone to higher managerial responsibilities.

The need for better interpretation and presentation of evidence is so great that it warrants emphasis. We are familiar with the reaction, "Yes, these are the results. So what do they mean?" The conclusions which seem so evident to the experimenter or the analyst must be translated into management terms—yields, construction costs, manpower requirements, and dollar savings. Graphic means of presentation are among the best means that can be used. If charts are used, however, they must visualize the facts readily. Quality control engineers have run up against the inability of management to *read* control charts. This is an example of how even a very useful tool can fail to be completely effective. Terms and forms familiar to management must be used so that the intent of the graphic presentation will be clear even to the casual viewer. The development of these means of influencing management decisions requires a high degree of ingenuity. Qualities not commonly appreciated as being associated with this kind of work may have to be developed.

PLANNED EXPERIMENTS

It is essential to start from the very beginning of an investigation with a well thought-out plan. Table 2 presents "The ABC's of Experimentation" which provide a step-by-step procedure.

TABLE 2—**The A B C's of Experimentation**

Part 1

A—Obtain a clear statement of the problem.
B—Tabulate all available information.
C—Design the experiment in preliminary form.
D—Review this design with all concerned.
E—Final design.

Part 2

F—Plan for experimental work.
G—Carry out experimental work.
H—Analyze data.
I—Interpret data.
J—Write report.

For this outline, which has been used widely in chemical development work, we are indebted to Dr. Martin A. Brumbaugh.[2] Although it

*Presented at the all-day Conference on Quality Control sponsored by the Metropolitan Section, ASQC, and Rutgers University at New Brunswick, N. J., September 16, 1950.

**Formerly with Hercules Powder Company.

[1]R. S. Fisher, Rothamsted Experimental Station in England, was the first proponent of the methods in his renowned book, "The Design of Experiments", Oliver and Boyd, London.

[2]Dr. Brumbaugh is Director of Statistics, Bristol Laboratories, Syracuse, New York.

may seem very simple to experienced researchers, it provides a very workable plan which is useful whether the work is done by statistical methods or not. It has been observed that the first five steps are frequently neglected in some measure, so that the last five steps are too frequently a waste of time and effort. Perhaps the key to the first half of the procedure is Step D, in which all who might be concerned with the final results confer in a review of the plan. During this conference, a clear statement should be made of what the alternative interpretations of the data obtained could be, ahead of actually obtaining such data. If these alternatives do not provide an answer to the problem, the design may be adjusted so that the problem which all interested parties are trying to solve is actually met in the work performed.

This is one way of saying that all the information required for development of a product must be built into the experiment design or into a series of such designs. Information which is not inherent in the data cannot be extracted merely by the application of statistical analysis. Failure to obtain sufficient measurements or the right ones may make the last half of the ABC's meaningless. It is also the reason why the research engineer often can be of little use to researchers who have undertaken an important program with an inadequate design[3] and find themselves with a mass of data of uncertain interpretation.

Table 3 gives a list of the principal items of information that may be built into a good experiment design.

TABLE 3—**Information Built Into a Good Experiment Design**

1—Effects of the factors studied.
2—Effects of inter-relationships among the factors.
3—Size of the experimental error.
4—Effects of sampling and testing if of interest.
5—Knowledge that all other factors are controlled or their effects randomized.

[3]An example of an inadequate design is the so called "classical" type in which one factor at a time is varied while all others are held constant. It is inadequate because it is incapable of uncovering inter-relationships and because it requires otherwise unnecessary repetition of runs to determine experimental error.

[4]A factorial experiment is one in which all possible combinations of the chosen levels of all the factors under study are investigated.

TABLE 4—**Experiment Design for Development of Plastic Film of Improved Luster—Stages A to E**

Factors to be Studied		
Materials	M_1 = Type P	M_2 = Type L
Thickness of Film	T_1 = 1 Mil	T_2 = 2 Mil
Drying Conditions	D_1 = Regular	D_2 = Special
Lengths of Wash	L_1 = 20 Min.	L_2 = 30 Min.
	L_3 = 40 Min.	L_4 = 60 Min.
Temperatures of Wash	W_1 = 92° C.	W_2 = 100° C.

Batches of Material B_1 and B_2 prepared on Different Days.
Total number of runs, 128.

It is sometimes possible to set up a factorial[4] experiment which will give all the elements of information listed in Table 3, or more. More often, part of the information, such as test and sampling errors, may be obtained from past experience or from independent investigation. The development chemist must decide what factors are likely to be of most interest and whether any or all possible interactions of those factors would have meaning to him. Decisions concerning the measurement of error and control of sampling and testing variation are handled with more facility by the statistical specialist. Good teamwork is developed to its most effective peak when the statistician sits in on the review of proposed research and development projects.

It is at this point in planning that experimentation may be minimized by use of special devices in setting up the design. There are various kinds of balanced incomplete designs that may be used. It must be recognized, however, that each limitation in the size of the experiment results in the loss of some information. Only an intimate knowledge of the capabilities and short-comings of the various designs will permit their use with certainty of the outcome. Careful planning must go into this phase of the design as well as into choice of the main factors to be studied. It is desirable to take advantage of reduced experimentation, even to the point where all information of secondary interest is excluded. However, even if it is found necessary to use a full factorial design more information is obtained than from an equivalent amount of experimentation using methods that were formerly popular. Most important is the fact that all information necessary for making an intelligent decision comes from the completed factorial design.

A PLANNED EXPERIMENT ILLUSTRATING TABLE 2—PART 2

The nature of the contributions of statistical methods to development work may be understood better by consideration of an actual problem. As has been pointed out, the procedure has at least two major parts; first, the activities leading up to the final design of the experiment and second, the actual conduct of the ex-

TABLE 5—**Experiment Design for Development of Plastic Film of Improved Luster—Stages F and G**
Experimental Results—Part 1, Material Type P, Luster Reading

Minutes	1 Mil							
	REGULAR DRY				SPECIAL DRY			
	92°		100°		92°		100°	
	B_1	B_2	B_1	B_2	B_1	B_2	B_1	B_2
20	3.4	3.4	19.6	14.5	2.1	3.8	17.2	13.4
30	4.1	4.1	17.5	17.0	4.0	4.6	13.5	14.3
40	4.9	4.2	17.6	15.2	5.1	3.3	16.0	17.8
60	5.0	4.9	20.9	17.1	8.1	4.3	17.5	13.9
	2 Mil							
20	5.5	3.7	26.6	29.5	4.5	4.5	25.6	22.5
30	5.7	6.1	31.6	30.2	5.9	5.9	29.2	29.8
40	5.6	5.6	30.5	30.2	5.5	5.8	32.6	27.4
60	7.2	6.0	31.4	29.6	8.0	9.9	33.5	29.5

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1000 PER HOUR

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2000 PER HOUR

5 DIMENSIONS
3600 PER HOUR

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TABLE 6—**Experiment Design for Development of Plastic Film of Improved Luster—Stage II Analysis of Data—Part 1, Material Type P, Explanation of Variation**

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	"F" RATIO	PROBABILITY OF SIGNIFICANCE
Temperatures	501,972	1	501,972	—	Very High
Film Thickness	83,810	1	83,810	1.7	None
Length of Wash	6,930	3	2,310	8.7	99.9%
Drying Conditions	663	1	663	—	None
Temp. & Thickness	50,513	1	50,513	189.3	99.9%
Temp. & Drying	1,600	1	1,600	6.0	95%
Experimental Error	14,699	55	267		
Total	660,187	63			

TABLE 7—**Experiment Design for Development of Plastic Film of Improved Luster—Stage II Analysis of Data—Material Type P at 92° C.—Explanation of Variation**

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	"F" RATIO	PROBABILITY OF SIGNIFICANCE
Film Thickness	2,096	1	2,096	24.1	99.9%
Length of Wash	3,162	3	1,054	12.1	99.9%
Drying Conditions	102	1	102	1.2	None
Experimental Error	2,268	26	87		
Total	7,628	31			

TABLE 8—**Experiment Design for Development of Plastic Film of Improved Luster—Stage II Analysis of Data—Material Type P at 100° C.—Explanation of Variation**

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	"F" RATIO	PROBABILITY OF SIGNIFICANCE
Film Thickness	132,266	1	132,226	283.0	99.9%
Length of Wash	4,078	3	1,359	2.9	95%
Drying Conditions	2,161	1	2,161	4.6	95%
Experimental Error	12,122	26	467		
Total	150,587	31			

periment and interpretation and reporting of results. The illustrative problem has to do with the development of a plastic film of improved luster. Following the steps in the first half of Table 2, a plan for the factors to be studied in a factorial design was arrived at as shown in Table 4.

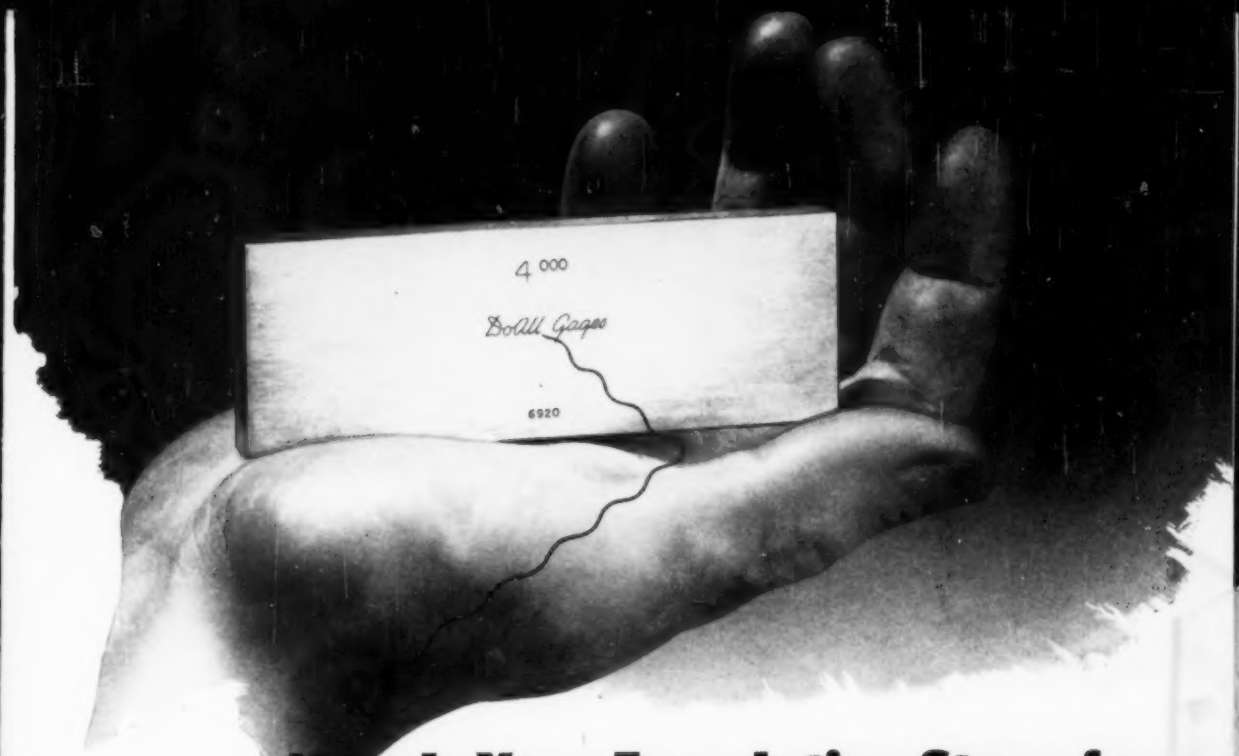
Five factors were chosen for study, four of them at two levels and one at four levels. Also, since batches of material made on different days were expected to give different results, it was planned to replicate (repeat) each run by preparing batches and making duplicate runs on two days. Thus the total number of runs was 128. This plan was carried out and the resultant data, ready for analysis, were arranged as shown in Table 5. For the sake of simplicity, only the first half of the data is shown.

The major problems of the interpretation and presentation of results crop up at this point. It is sometimes possible in presenting results to make use of the variance table as used by statisticians in the analysis of variance technique.[5] It has the disadvantage of employing specialized terms. Without somewhat lengthy accompanying explanations it may not be understood. However, since the variance table is an inherent step in a complete analysis of variance and because it is a useful form of report in some situations, it is presented as a possible form for reporting and interpreting results. The principal variance table for the illustrative problem is show in Table 6.

This table is in somewhat reduced form, since only the main factors, significant interactions, and experimental errors are shown. The sums of squares may be looked at as the gross amount of variation explained by the various factors. The degrees of freedom represent factors which take into account the amount of data. The mean squares may be thought of as the net effects of the various factors. The "F" ratios represent the relationship of the factors to the error incurred in determination of their effects. The probability of significance column represents the probability that the effect of the factor is real or significant in light of the size of the "F" ratio. Probability is read from Tables for the "F" Ratio.[6] The question of what is sig-

[5]For an alternative method of analysis see "Statistics in Engineering, Research and Development." Ellis R. Ott, 110th Annual Meeting, American Statistical Association, Chicago, Dec. 28, 1950.

[6]These tables are available in most standard statistical texts. A useful source for research and development chemists is K. A. Brownlee's "Industrial Experimentation" 4th ed., (1949) Chemical Publishing Co., New York.



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nificant and what is not is an important one and will be discussed after the next two tables are considered.

Perhaps the key information coming from Table 6 is that there are two significant interactions involving Temperatures. This means that the analysis must be broken down into two parts, one for each level of Temperature. This procedure results in two more variance tables; Table 7 for 92° C. temperatures, and Table 8 for 100° C. temperatures.

Before going into a complete explanation of these tables it is desirable to make some explanation of an acceptable probability level. In these tables a probability of 95% was required for any effect to be considered significant. Choice of this level, although somewhat arbitrary, has the backing of commonly accepted practice and has proved to be workable in actual situations. As a guide to what may be considered acceptable risks in chemical development as the work progresses through various stages, Table 9 is presented.

TABLE 9—**Acceptable Risks in Chemical Development**

Stage of Development	Probability of Real Effect
Basic Research	Over 50%
Laboratory Development	65-95%
Pilot Plant	95% or over
Process Control	99.7%

The answers to most of the important questions asked in the problem of improving film luster are given in the three tables, numbers 6, 7, and 8. However, some verbal explanation should surely accompany presentation of these tables. With the added advantage of information from a similar anlysis of data using the second material, Type L, such verbal explanation might run as follows:

1. Type P Material gave higher luster values than Type L.
2. For Type P Material, the 2 Mil. film gave higher luster values than the 1 Mil. film regardless of temperature. Combining the effects of the two temperatures made it impossible to distinguish between the two thicknesses. This was because of the greater sensitivity of luster to film thickness at higher temperatures.
3. For Type P Material, there was no difference between the Regular and Special drying cycle at 92° C. At 100° C., however, luster values for the Regular cycle were higher than for the Special cycle. The margin of this difference was small, however. Combining the two temperatures made it impossible to distinguish between the Regular and Special cycles.
4. For Type P Material, the time of washing has a significant effect on luster at both 92° C., and 100° C. Luster at 60 minutes is higher than for 40 or 30 minutes and, for these two intermediate times, higher than for 20 minutes. The difference between 30 and 40 minutes is not significant.
5. For Type P Material, 100° C. gave higher luster than 92° C. The difference is so great that it is significant in spite of the interaction of Temperature with Thickness and Drying Cycle.

The several effects studied may be rated in importance of their effect on luster, as follows:

1st—Temperature of wash.
2nd—Thickness of film.
3rd—Time of Washing.
4th—Type of Material.
5th—Drying (Important only at 100° C.)

TABLE 10—**Experiment Design for Development of Plastic Film of Improved Luster**
Interpretation and Presentation of Data—Tabular Method—Part 1

COMPARISON	AVERAGE LUSTER	PROBABILITY OF REAL DIFFERENCE	LEAST SIGNIFICANT DIFFERENCE
Materials	Type P = 14.0	99.9%	1.4
	Type L = 8.6		
Temperature of Wash	92° C. = 5.2	99.9%	1.7
	100° C. = 22.9		
Thickness @ 92° C. Wash	1 Mil. = 4.3	99.9%	0.7
	2 Mil. = 6.0		
Thickness @ 100° C. Wash	1 Mil. = 16.4	99.9%	1.4
	2 Mil. = 29.3		
Drying @ 92° C. Wash	Regular = 5.0		
	Special = 5.3	80%	0.7
Drying @ 100° C. Wash	Regular = 23.7		
	Special = 22.0	95%	1.4
Length of Wash @ 92° C.	20 Min. = 3.9		
	30 Min. = 5.0		
	40 Min. = 5.0		
	60 Min. = 6.7	99.9%	1.0
Length of Wash @ 100° C.	20 Min. = 21.1		
	30 Min. = 22.8		
	40 Min. = 23.4		
	60 Min. = 24.2	95%	2.0

A tabular method of presenting a maximum amount of information is provided, without further comment, in Table 10.

Finally, a graphic method. Parts 1 to 5. is presented as one means of reporting visually the results of the experimentation to improve luster of plastic film. As a suitable graphic form, these charts should provide a clear summary of the work and permit selection of appropriate conditions for producing the improved luster. Unless the tabular, verbal, or graphic conclusions convey information in understandable, usable form, a considerable part of the value of experimental work is lost.

It still remains for the experimenter to make recommendations regarding the most advantageous

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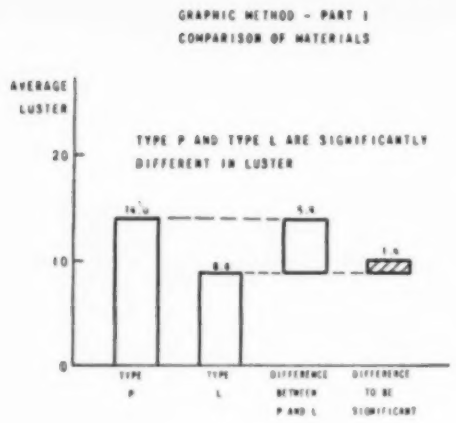
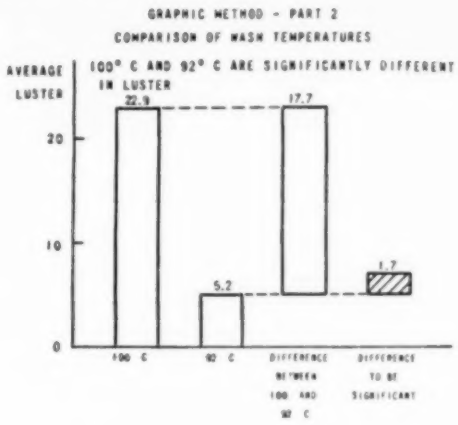
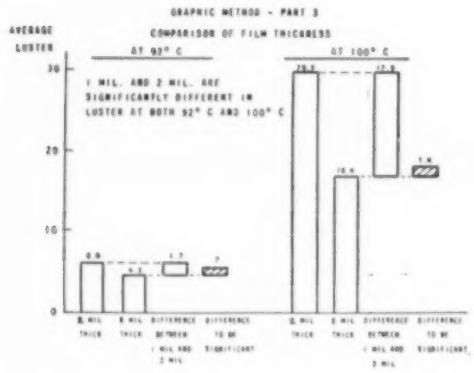
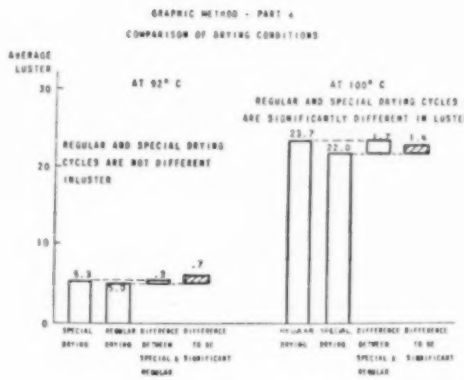


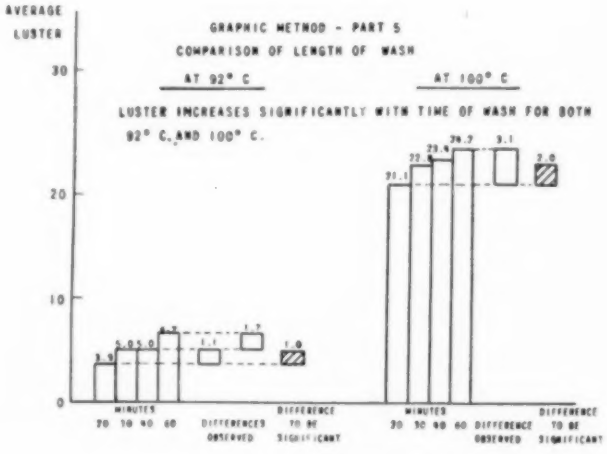






and economical choice of conditions for manufacture of the plastic film. It will be necessary, for example, to determine whether a high or low luster is required for the intended use of the film. Next, the relative availability and cost of Materials Type P and Type L must be considered. The wide difference between the 92° and 100° temperatures may make the choice between them self-evident. However, cost and ease of control at the different temperatures may be worth considering.

When the two principal decisions concerning material and wash temperatures are made, similar decisions must be made regarding the other significant factors. Suppose, for purpose of discussion, that high luster characteristics were desired. The



choice of Type P material, cost and availability permitting, is indicated clearly by the Part 1 diagram. There is similar lack of hesitancy in choice of 100° C. wash temperatures when the Part 2 diagram is consulted.

The Part 3 diagram shows that 2 mil. thickness is preferable and, if this meets end use specifications, the thicker film should be specified. Reference to the Part 4 diagram shows that the Regular Drying Cycle is better, so that cost and availability of special equipment does not enter into this decision. Finally, since 100° C. temperature has been chosen, there is some advantage in a 60 minute washing period, as shown in the Part 5 diagram. However, the advantages due to regular drying and longer wash are small in terms of absolute luster readings and economic considerations may outweigh the statistical evidence of superiority.

No development work may be considered completed until it is carried all the way to an executive decision. All along the line, from statement of the problem to the interpretation and presentation of the data, the use of statistical methods has been shown to contribute an extremely beneficial effect.

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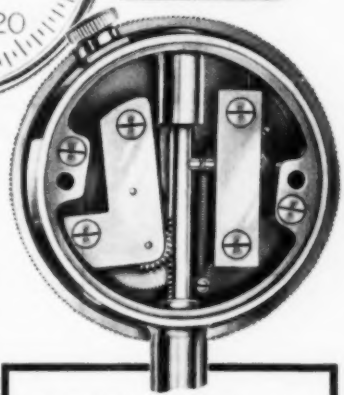

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If a company makes washing machines, bicycles, electric shavers, cameras, or dial telephones—in fact any of the vast array of relatively complicated products—what is the best way to set up a control on the over-all quality of the product? The idea of using percent defective will probably be dropped as soon as you have considered the prospect of classifying an entire washing machine as a defective! And while variables control charts are wonderfully useful devices, there are many quality requirements that will not fit handily into $\bar{X}$ and R.

When the probability of finding a fault in a product is small in relation to the opportunity for faults to occur, it is possible to use a "c" chart for defects per unit. This comes closer to what we want, because it allows us to group all the different kinds of faults together into one figure representing each unit inspected. But it has the serious drawback that a minor fault will carry the same weight as a major departure from quality requirements.

The problem, therefore, is to set up a control that will take into account the seriousness of a defect as well as its frequency. Mr. H. F. Dodge outlined the solution in "A Method of Rating Manufactured Product" in The Bell System Technical Journal, April, 1928. Mr. A. G. Dalton's booklet titled "Quality Controls Employed by Western Electric" indicates that the method has been used successfully for many years for a final quality audit covering some 220 classes of manufactured product. At Federal Telephone and Radio we found this approach to the quality problem extremely useful and believe that the method can be applied to a wide variety of products.

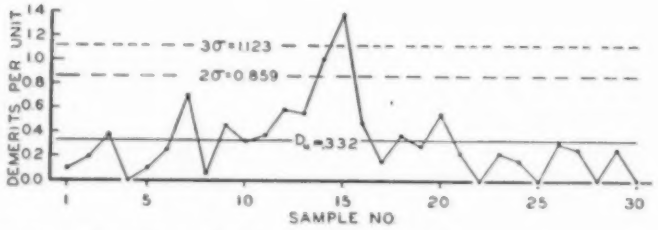


Figure 1—**Demerits per Unit for 30 Samples, n = 100**

The many independent quality requirements of a product have one characteristic in common: the effect of non-conformance on the user. This point of view allows us to divide the faults found in inspection into several classes graded from least serious to most serious in terms of consumer reaction. For many products only two classes, Major and Minor, will be sufficient. It is hard to think of a product so complicated that its possible faults could not be fitted reasonably into the four following classifications.

Classification of Defects

Class 1—Very Serious or Critical Defects

The customer will refuse to buy the product.

The product will surely fail in use and the fault cannot readily be repaired.

The fault may cause injury or damage.

Class 2—Serious or Major "A" Defects

The customer will certainly be dissatisfied with his purchase.

The product will probably but not surely fail in use.

The fault will surely cause decreased life or require excessive servicing.

Class 3—Moderately Serious or Major "B" Defects

Likely to cause loss of efficiency in use, but not operating failure.

Likely to cause decreased life or require excessive servicing.

Faults of appearance, finish, and workmanship that make the product less desirable.

Class 4—Not Serious or Minor Defects

Minor defects of appearance, finish, or workmanship.

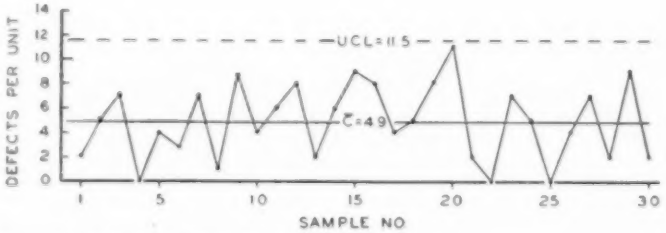
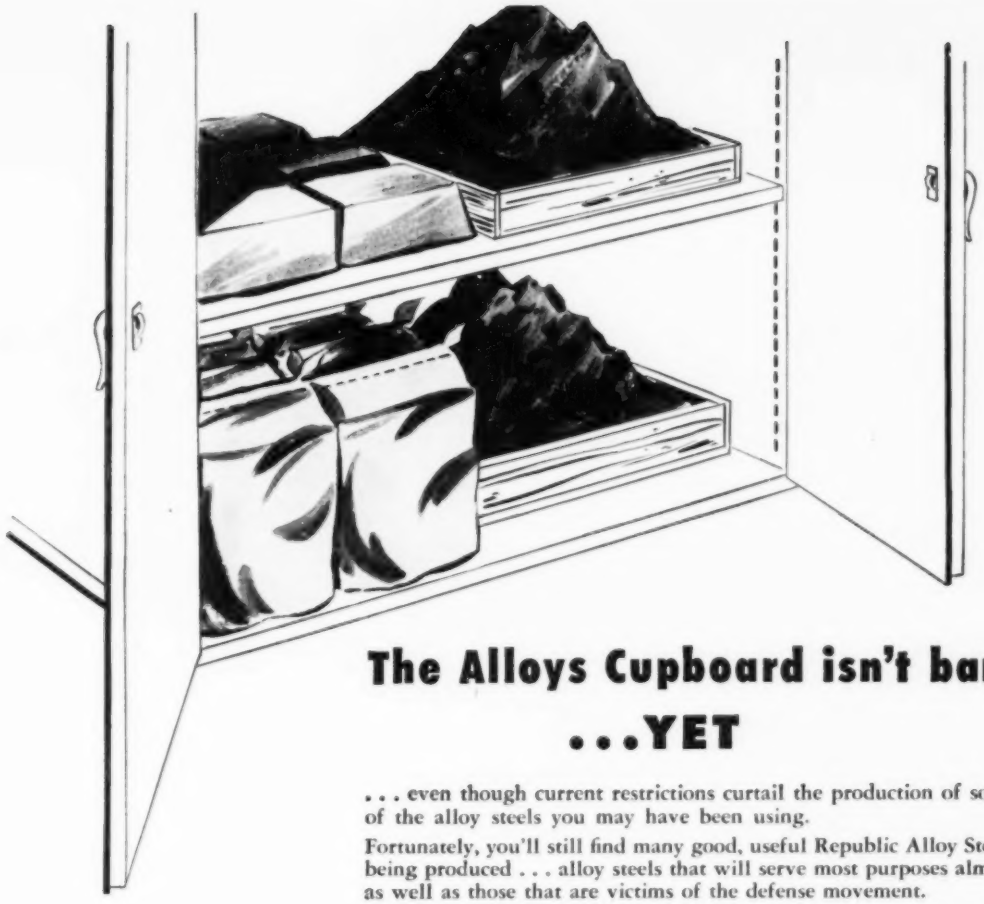


Figure 2—**Defects per Unit (Unit = 100 assemblies)**

* Paper presented to California Section, ASQC, Sept. 1950. This paper is a revised draft of a paper previously presented to Metropolitan Section, ASQC, which was released for presentation by Federal Telephone and Radio Corporation. The author was Chief Quality Control Engineer for this company during the period that the system described in this paper was installed.



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Faults that will not cause failure in service, decreased life or excessive servicing.

When the quality requirements have been classified, the relative seriousness of each class is expressed by an assigned weight. The scale of weights used can be arbitrary; only the relative weights and the frequency of occurrence for each class of defects will concern us. The cost of a class of defects in terms of repair, replacement, or customer service will probably influence the choice of weights. These weights have been given the term "demerits", and those used in this discussion are as follows:

Class 1.....50 demerits
Class 2.....20 demerits
Class 3..... 5 demerits
Class 4..... 1 demerit

It may be useful in the case of a variable characteristic to assign two or more demerit weights according to the degree of non-conformance. For each unit inspected the number of defects found in each class is multiplied by the assigned weight for the class, and the sum of the weighted defects is the demerit rating for the unit.

Figure 1 shows the result of inspecting 30 samples of 100 assemblies each. Each point is the average demerits per assembly for the sample. Sample number 15 has fallen outside the control limits and calls for investigation. However, we should be willing to run some risk of investigating smoke without finding fire, and the best place to start checking is at Sample No. 14, which has fallen outside of two standard deviations. It is interesting to note that the chart in Figure 2, which is the same 30 samples on a defect per unit basis (the unit being 100 assemblies) would not have flashed a red light when it was needed, and might have stirred us up unnecessarily at Sample No. 20, when the eleven faults found were of a minor nature.

The average and limits on the chart in Figure 1 were derived from the data of the 30 samples in order to illustrate the process. Table 1 shows the computations necessary to set up limits. Table No. 2 gives the data for four of the points on the chart.

It should be noted that the assumption is made that the d's are independent variables subject to sampling variations; also that the ratio of d to the possible number of defects is small so that we can assume $\sigma_d = \sqrt{d}$.

TABLE 1

Class No.	Weight w	No. Defects d	wd	w^2	w^2d	d/n_r
1	50	5	250	2500	12500	.0017
2	20	16	320	400	6400	.0053
3	5	75	375	25	1875	.0250
4	1	52	52	1	52	.0173
			997		20827	

w = assigned weight
d = number of defects observed
n = number of units in sample
n_r = number of units in base period = 30 x 100 = 3000
D_u = average demerits per unit = wd/n_r = 997/3000 = 0.332
C_s = constant of variance = w^2d/n_r = 20827/3000 = 6.94

$\sigma(D_u) = \sqrt{C_s/n}$ $\quad D_u \pm 3\sqrt{C_s/n}$ $\quad D_u \pm 2\sqrt{C_s/n}$

$.332 \pm 3\sqrt{6.94/100}$ $\quad .332 \pm 2\sqrt{6.94/100}$

3σ-Upper Limit = 1.123 $\quad$ 2σ-Upper Limit = 0.859
3σ-Lower Limit = 0 $\quad$ 2σ-Lower Limit = 0

Many of the assemblies required considerable skill on the part of the operator in assembling components and adjusting them to meet operational requirements. The chart in Figure 3 shows a 30 week period during the early stages of installing a demerit system. Each point represents 4000 to 6000 assemblies presented for inspection by almost 50 operators. The rather steep drop in demerits during the first month was the result of a concerted effort to put across the idea that the operator is responsible for quality. Everyone was fully advised of the demerit weight for each type of fault. A weekly report was issued to show the demerits per unit for each operator, which could be compared with the average for the group. The foremen followed up by concentrating their training effort on those operators that needed it most.

The pattern of a decided drop in faults found, followed by a leveling off, was repeated on a number of assembly lines. When this second stage is reached, the really hard work begins. If the new level of quality is satisfactory, the next effort will be to bring it into control. The trial control limits on the last 20 weeks in Figure 3 show that more effort will be necessary before consistent quality is achieved.

In Figure 3 the variations in number inspected did not influence the control limits enough to change the number of points that were outside the limits. The chart in Figure 4 is on a daily basis and the control limits have been adjusted for the most extreme variations in quantity inspected. The central line is an Ex-

TABLE 2

Sample No		5		10		15		20	
Class	w	d	wd	d	wd	d	wd	d	wd
1	50	0	0	0	0	2	100	0	0
2	20	0	0	1	20	1	20	1	20
3	5	2	10	2	10	3	15	6	30
4	1	2	2	1	1	3	3	4	4
Total Demerits			12		31		138		54
Total Demerits/100			.12		.31		1.38		.54

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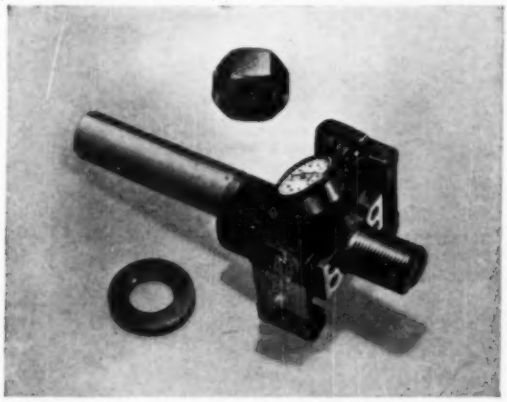

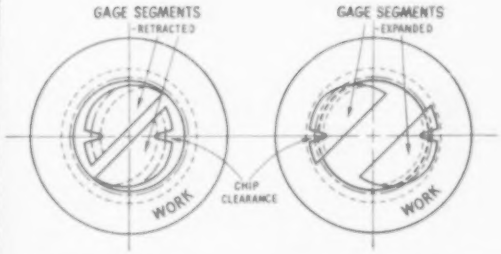

Plug segments are collapsed so gage may be inserted or withdrawn without threading.

Plug segments are expanded to give full length contact on all the threads.

The new Bryant internal thread gage is based on the principle of a split plug gage. The plug segments are collapsed by a thumb lever and inserted into the threaded hole. When the thumb lever is released, the plug segments expand to contact the internal threads in the parts being inspected.

This new gage is portable, therefore, threads may be checked while the part is chucked in a machine, and it offers extra convenience when inspecting threads in large, heavy casting that cannot be moved conveniently.

The Bryant gage is designed to give one accumulated reading of P. D., form and lead on the dial indicator. For the first time it is now possible to sort parts into known classifications for fit (assemble-ability). This gage is used for the inspection of internal threads in a range from 5/16" to 1" diameter. Interchangeable segments are easily attached to the gage to cover a wide range of thread sizes. These segments are made to the same tolerances in P. D., lead, and form as a Class "W" Master. The life of the segments is lengthened by the fact that the gage does not have to be screwed into or out of the threaded hole — a partial turn gives a full reading on all the elements of all the threads.

Actual tests show that the Bryant portable internal thread gage will check parts four to five times faster than the standard plug gage!

MAIL THE COUPON FOR FURTHER INFORMATION

COUPON

Please send me complete details on the New Bryant Portable Thread Gage.

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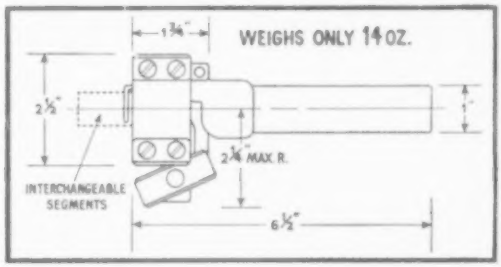
COMPANY_____

STREET_____

CITY_____ STATE_____



BRYANT

CHUCKING GRINDER CO.

SPRINGFIELD, VERMONT, U. S. A.

pected Average of demerits per unit $(D_u)_s$. It is based on accumulated experience modified by engineering judgment as to the quality level that can be maintained on an economic basis.

The chart in Figure 5* presents the same data in terms of standard deviations. The Expected Average becomes a Normal of zero. Each day's work has been tested against the assumption that it will contain the Normal number of demerits per unit and the chart records the number of standard deviations (t) by which the result is better (+) or worse (—) than Normal.

$$t = \frac{\left(\begin{matrix}\text{Expected}\\ \text{Demerits}\end{matrix}\right) - \left(\begin{matrix}\text{Actual}\\ \text{Demerits}\end{matrix}\right)}{\sqrt{n\,C_s}}$$

$$\text{Expected Demerits} = n(D_u)_s$$

With this chart we can follow the variations of quality in relation to either 2 or 3 sigma limits without the nuisance of adjusting for sample size. The work of individual operators for a day, week, or month can also be given a plus or minus quality rating that can be compared directly with that of his group. The work of one group can be compared with that of another, even though the products are quite different, assuming, of course, that the system of demerit weights is universal and consistent for the two products. These charts can be very useful for management reports.

In setting up and using a demerit rating system, we found that benefits result from each step in the process. The act of listing and weighting the quality requirements helped to clarify our objectives. The systematic reporting of reasons for rejection enabled us to focus corrective effort where it was needed most. The follow-up resulted in better trained operators, better material and methods supplied to the assembly lines, and an increased understanding of the responsibility for producing acceptable work. Finally, the establishment of Expected Quality Standards helped us to do some realistic thinking about the cost of quality in relation to the value of quality.

*The vertical scale on this chart has been intentionally reversed to make the variation pattern directly comparable to that on the chart in Figure 4. In practice, this Deviations Chart has the positive t values *above* and the negative t values *below* the Normal or zero line.

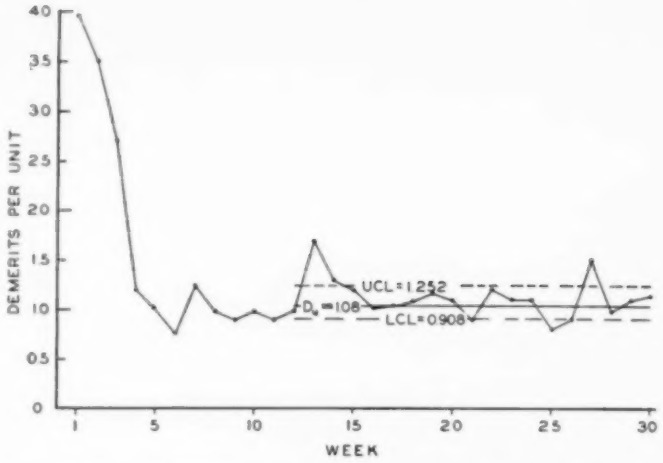


Figure 3—**Demerits per Unit; Period covered: 30 weeks; Average production per week: 5000; 100% inspection of work of 46 operators.**

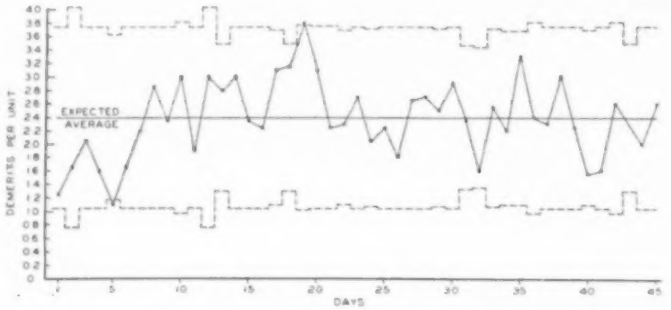


Figure 4—**Demerits per Unit, Daily Basis**

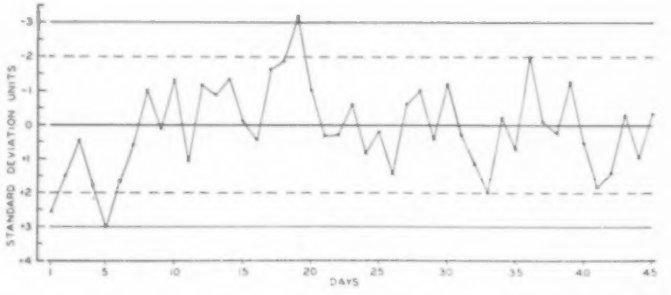
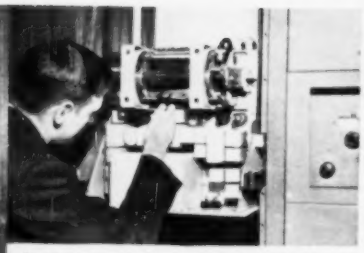


Figure 5—**Deviations from Expected Average in Standard Deviation Units**

References

H. F. Dodge, "A Method of Rating Manufactured Products"; Bell Telephone Laboratories, Reprint B315.

Electrical Engineering, March, 1946. "Statistical Methods in Quality Control"; No. X—"Classification of Defects and Quality Rating".



Each crystal is enclosed in a cylindrical oven which holds the crystal temperature to within 1/100 of a degree.

At the A. T. & T. building at 195 Broadway, New York, passersby set watches by the world's most accurate public clock, which is controlled by the master standard.

▲ Front of the new frequency-time standard at Bell Telephone Laboratories. In the rear there are 600 electron tubes and 25,000 soldered connections. Room temperature is maintained within two degrees.

The controlling quartz crystal vibrates in vacuum at 100,000 cycles per second. The standard is powered by storage batteries, with steam turbo-generator standing by, just in case of emergency.

A vibrating crystal keeps master time

Ever since Galileo watched a lamp swinging in the Cathedral of Pisa three centuries ago, steady vibration has provided the practical measure of time. In the 1920s Bell Laboratories physicists proved that the quartz crystal oscillators they had developed to control electrical vibration frequency in your telephone system could pace out time more accurately than ever before.

The Laboratories' latest master standard keeps an electric current vibrating at a frequency that varies only one part in a billion, keeping time to one ten-thousandth second a day.

Through secondary standards, a master oscillator governs the carrier frequencies of the Bell System's ship-to-shore, overseas and mobile radio-telephone services, the coaxial and *Radio Relay* systems which transmit hundreds of simultaneous conversations, or television. In the northeastern states, it keeps electric clocks on time through check signals supplied to electric light and power companies.

The new standard also provides an independent reference for time measurements made by the U. S. Naval Observatory and the National Bureau of Standards. Thus, world science benefits from a Laboratories development originally aimed at producing more and better telephone service.

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The Use of Limit Gages in Process Control*

ARTHUR E. MACE

American Steel & Wire Company

SAMPLING inspection with limit gages on each machine operation is designed to give the operator a practical guide to machine adjustment which will avoid the pitfalls of the ordinary go and no-go gage procedures. Essentially such inspection procedure is based on the recognition that there is bound to be a certain predictable variation in a series of consecutive units produced within a relatively short period of time. By placing a limit on the number of units in a small sample of consecutive units which may fall either above or below established gage limits, it is possible to maintain practically all units within engineering specifications[1] with a minimum amount of machine adjustment.

A common sampling inspection procedure with limit gages calls for a machine adjustment whenever three or more out of a sample of five consecutive units produced fall either above or below the control limits for an X chart based on a sample of five (i.e. $\bar{X}' \pm 1.34\sigma'$ or $\bar{X}' \pm 0.58R'$). Such an inspection procedure requires merely the substitution of go and no-go gages with somewhat narrower limits than the engineering tolerances. It is the purpose of this article to demonstrate that for stable processes[2] such a sampling plan for use with limit gages affords almost as much protection against producing defective units as does a sampling plan based on dimensional gaging of five consecutive units with a dial indicator, and does so with but slightly more machine adjustment.

First, it is necessary to determine exactly how much protection is afforded and the number of machine adjustments likely to be required by a sampling plan based on dimensional gaging of five consecutive units with control limits on $\bar{X}$ at $\pm 1.34\sigma'$ from the specification mean, which we henceforth take to be zero.[3]

Table 1 gives data from which to construct the operating characteristic curve for this plan. The calculations in Table 1 and subsequent tables in this paper are based on the following assumptions:

1. The process standard deviation, σ', is constant. It is not subject to trends that increase or decrease its value. Shifts in the process are entirely shifts in process level, $\bar{X}'$.
2. The process standard deviation, σ', has been estimated from a machine capability study.
3. The control or gage limits for any given sampling plan are equidistant from the specification mean by a multiple of the estimated process standard deviation.
4. The frequency distribution of the quality characteristic is normal.

Under these assumptions the third column of this table gives the probability that a sample $\bar{X}$ will fall within the established control limits if the process mean is at the level given in the first column. For example, if the process mean is 1.0 standard deviation above the specification mean, the lower control limit on $\bar{X}$ will be 2.34 standard deviations below the process mean, the upper control limit of $\bar{X}$ will be 0.34 standard deviations above the process mean, and 0.7776 of the sample $\bar{X}$'s may be expected to fall

(Continued on page 28)

TABLE 1—OC Curve Data for $\bar{X}$ Control Chart Used as a Constant-Sigma Variables Acceptance Plan (Sample Size n = 5)

Process Mean (in standard deviations from specification mean)	Maximum Percent Defective in Process*	Probability of Non-Machine Adjustment	Probability of Machine Adjustment
0.0	0.27	.9973	.0027
0.5	0.64	.9701	.0299
1.0	2.28	.7776	.2224
1.5	6.68	.3617	.6383
2.0	15.87	.0705	.9295
2.5	30.85	.0048	.9952
3.0	50.00	.0001	.9999
3.5	69.15	.0000	1.0000

*The calculation of maximum percent defective in process is based on the additional assumption that process spread equals total tolerance.

[1] This assumes, of course, that engineering specifications are consistent with machine capability. The process spread (usually estimated as six standard deviations) must not be larger than total tolerance.

[2] A stable process will be one in which the standard deviation is constant. Provided it is known that the process is stable, the standard deviation can be estimated from a machine capability study involving the dimensional gaging of at least 30 units before either gage limits or control limits are calculated. Provisionally, however, gage limits or control limits may be based on the maximum standard deviation that is consistent with engineering specifications—a standard deviation which is one-sixth of total tolerance.

[3] In these and subsequent calculations it is assumed that the purpose of the control plan, whether it involve dimensional gaging or limit gaging, is to maintain all units as close to specification mean as is consistent with machine capability, regardless of engineering tolerances. This assumption will be relaxed in a discussion of modified control limits at the end of the paper.

*Research in connection with this article was undertaken while the author was employed as an associate consultant with the firm of Dr. J. N. Berrettoni and Associates, consultants in statistical quality control. Valuable assistance in the original preparation of this article was contributed by Dr. J. N. Berrettoni.

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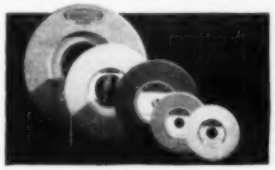
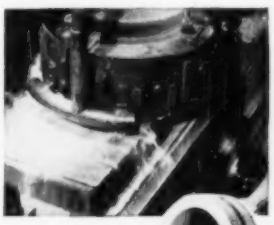


Straight Wheels



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Syracuse
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THE fastest-growing upstate New York city, Syracuse registered in the last census a ten-year population gain of more than 14,000 people; as many as Albany, Utica, Binghamton, Rochester, and Buffalo combined. In large part, this increase is due to its excellent position as a land, water, and air transportation junction.

More important even than this, however, has been its increasing and diversified industrial activity. Some 400 manufacturing plants, with an estimated total labor force of 60,000 (compared with 36,000 a decade ago), produce more than 500 different products valued at $600,000,000 annually. Their payrolls give the community an annual purchasing power of at least one billion dollars. New industries and the expansion of old ones are pouring additional millions into the economy of Syracuse and Onondaga County.

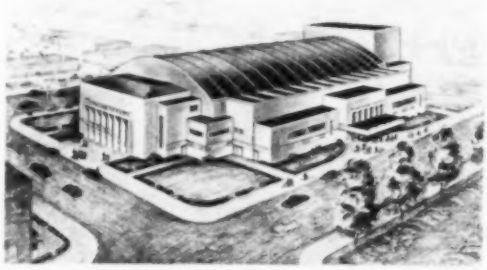
The high quality of the labor force of the area has been an additional strong attracting force for industries. During World War II, when Greater Syracuse produced a tremendous variety of war materials, ranging from tank clutches and fighting knives to machine guns and complex radar equipment, there was not one work stoppage in the city proper, and the perfect record of the county was marred by a stoppage of only a single day.

The Community Chest idea originated in Syracuse, and its current Civil Defense Program and activities have been made the basis for a nationally distributed film and are used as a reference by cities throughout the nation and the continent. The annual New York State Fair, held here during the first week in September, attracts thousands of visitors to the agricultural, commercial, and industrial exhibits; while the new $3\frac{1}{2}$ million dollar War Memorial Auditorium will help Syracuse become one of the leading convention cities in the East.

One of the first conventions able to use this beautiful new auditorium will be that of the American Society for Quality Control. Syracuse, through its many industries, has become a large and ever-increasing user of quality control methods, and is perhaps unique among cities in offering free instruction in these techniques to its citizens through the medium of adult education courses given in a local night school.

There are many facilities, including large and small hotels, tourist homes and courts, available for your comfort in the city and nearby. These accommodations will, however, be strained if the convention attendance exceeds 2500, so register early. Your registration fee will be refunded upon notification that you cannot attend.

Come to Syracuse for YOUR Convention on May 22, 23, and 24, 1952.



Architect's View of Onondaga County War Memorial Auditorium from the Northwest

General Electric—Electronics Park

New Thompson Road Plant of Carrier Corporation

AMERICAN SOCIETY FOR QUALITY CONTROL

SIXTH ANNUAL CONVENTION

SYRACUSE, NEW YORK

MAY 22, 23, 24, 1952

Address Reply to November 16, 1951

To All Members of A.S.Q.C. & Those Interested in Quality Control:

The Sixth Annual A.S.Q.C. Convention will be held in Syracuse on May 22, 23, & 24, 1952. Because of the continually expanding interest in Quality Control and the large growth of society membership in recent months, it has been decided to lengthen the convention to three days this year. This will give us an opportunity to present an even bigger and finer program than was possible in the past and will also allow more time to view the excellent exhibits which are being prepared for you.

The technical sessions have been planned so that seven programs will be in operation simultaneously at each of four two-hour periods. Some 60 papers on Quality Control applications and principles will be available. Included are sessions to service the society's industrial technical committees: Electronic and Electrical, Chemical, Textile, Automotive, Food and Aircraft.

In response to popular demand 11 hours of integrated educational program will be presented. This has been set up especially for those who have had no previous introduction to the principles and practices of Quality Control or for in-service personnel who wish a refresher in the subject.

The convention will be held in the new Onondaga War Memorial Auditorium where every effort has been made to provide facilities for our use which are as fine as any in the country.

We are presently arranging with the best dining caterers in Syracuse for our luncheons and banquet and we will endeavor to provide meals for all who wish them. However, we cannot emphasize too greatly the desirability of early registration. Estimating accurately the number of people who will want meals is probably the most difficult task of your committee. We, therefore, urge you to make your plans now to register as soon as you receive the registration blank. Your money will be returned if we are advised that you cannot attend.

The committee has been diligently at work for many months to make this the convention which will long be remembered for its outstanding quality in every category.

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Sincerely yours,

LB/gg

Leon Bass

LEON BASS

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within these control limits; i.e. if the process mean is 1.0 standard deviation above the specification mean, then: $P(-2.34\sigma' < \bar{X} < +0.34\sigma') = P(-5.236\sigma_{\bar{x}} < \bar{X} < +0.764\sigma_{\bar{x}}) = 0.7776$.[1] Similarly, 0.2224 of the sample $\bar{X}$'s may be expected to fall outside these control limits and thus call for a resetting of the machine.

Next, it is necessary to determine exactly how much protection is afforded and the number of machine adjustments likely to be required by a sampling plan which calls for a machine adjustment whenever three or more out of a sample of five consecutive units produced fall either above $+1.34\sigma'$ or below $-1.34\sigma'$, in other words, above or below the three-sigma limits for averages of five. The probability that one unit will fall outside one of these limits for any given setting of the process mean can be calculated by the use of a Table of Areas under the Normal Curve. The probability that three or more out of five units will fall outside one of these limits for any given setting of the process mean can then be calculated from the binomial distribution. The probability of acceptance for any given setting of the process mean will then be the probability that less than three out of five units fall either above or below gage limits set at $\pm 1.34\sigma'$.

Table 2 gives data from which the operating characteristic curve for this plan may be constructed, assuming the same conditions as stated for Table 1.

The third column of Table 2 gives the probability that less than three out of five units will fall either above or below gage limits set at $\pm 1.34\sigma'$ if the process mean is at the level given in the first column. For example, if the process mean is 0.5 standard deviations above the specification mean, the lower gage limit will be 1.84 standard deviations below the process mean, the probability that one unit will fall below this

[1]The expression $P(-2.34\sigma' < \bar{X} < +0.34\sigma')$, for example, is read: "The probability that $\bar{X}$ lies between $-2.34\sigma'$ and $0.34\sigma'$." Furthermore, $-2.34\sigma' = (-3/\sqrt{5} - 1)\sigma' = (-3/\sqrt{5} - 1)\sqrt{5}\sigma_{\bar{x}} = (-3 - \sqrt{5})\sigma_{\bar{x}} = -5.236\sigma_{\bar{x}}$ etc. Reference to a Table of Areas under the Normal Curve gives the required probabilities.

TABLE 2—OC Curve Data for Attribute Inspection With Limit Gages (Gage Limits GL = $\pm 1.34\sigma'$, n = 5, c = 2)

Process Mean (in standard deviations from specification mean)	Maximum Percent Defective in Process*	Probability of Non-Machine Adjustment	Probability of Machine Adjustment
0.0	0.27	.9873	.0127
0.5	0.64	.9414	.0586
1.0	2.28	.7380	.2620
1.5	6.68	.3820	.6180
2.0	15.87	.1084	.8916
2.5	30.85	.0153	.9847
3.0	50.00	.0010	.9990
3.5	69.15	.0001	.9999
4.0	84.13	.0000	1.0000

*The calculation of maximum percent defective in process is based on the additional assumption that process spread equals total tolerance.

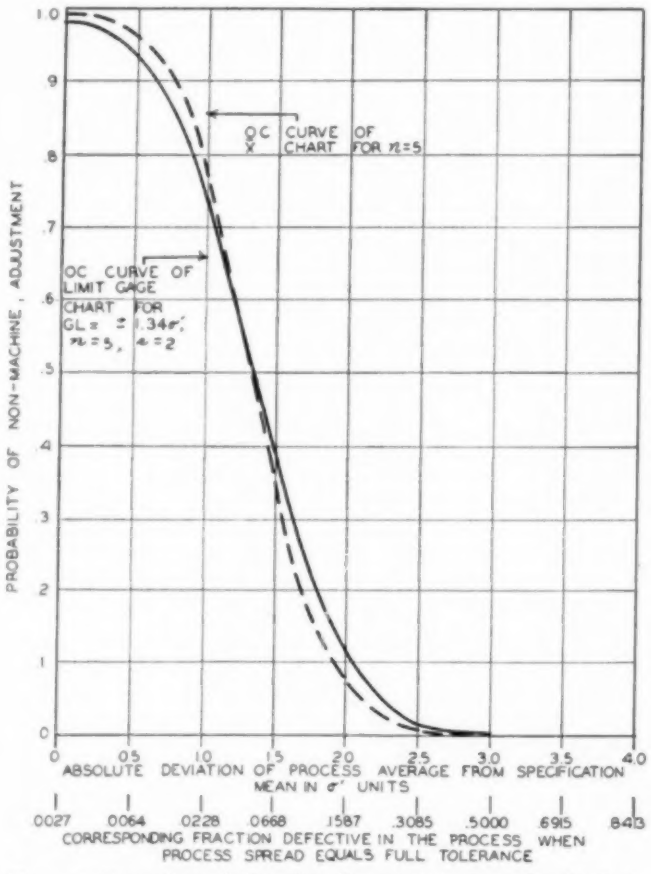
PROBABILITY OF NON-MACHINE ADJUSTMENT
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
OC CURVE OF X CHART FOR n=5
OC CURVE OF LIMIT GAGE CHART FOR GL = ±1.34σ', n=5, c=2
0 .5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
ABSOLUTE DEVIATION OF PROCESS AVERAGE FROM SPECIFICATION MEAN IN σ' UNITS
.0027 .0064 .0228 .0668 .1587 .3085 .5000 .6915 .8413
CORRESPONDING FRACTION DEFECTIVE IN THE PROCESS WHEN PROCESS SPREAD EQUALS FULL TOLERANCE

Figure 1—**Comparison of Operating Characteristic Curve for Attribute Inspection using Limit Gages (GL = $\pm 1.34\sigma'$, n = 5, c = 2) with that for Variables Inspection using $\bar{X}$ Chart (n = 5)**

TABLE 3—**OC Curve Data for Attribute Inspection with Limit Gages (Gage Limits GL = ±3.00σ′, n = 14, c = 0)**

Process Mean (in standard deviations from specification mean)	Maximum Percent Defective in Process*	Probability of Non-Machine Adjustment	Probability of Machine Adjustment
0.0	0.27	.9630	.0370
0.5	0.64	.9137	.0863
1.0	2.28	.7251	.2749
1.5	6.68	.3798	.6202
2.0	15.87	.0890	.9110
2.5	30.85	.0057	.9943
3.0	50.00	.0001	.9999
3.5	69.15	.0000	1.0000

*The calculation of maximum percent defective in process is based on the additional assumption that process spread equals total tolerance.

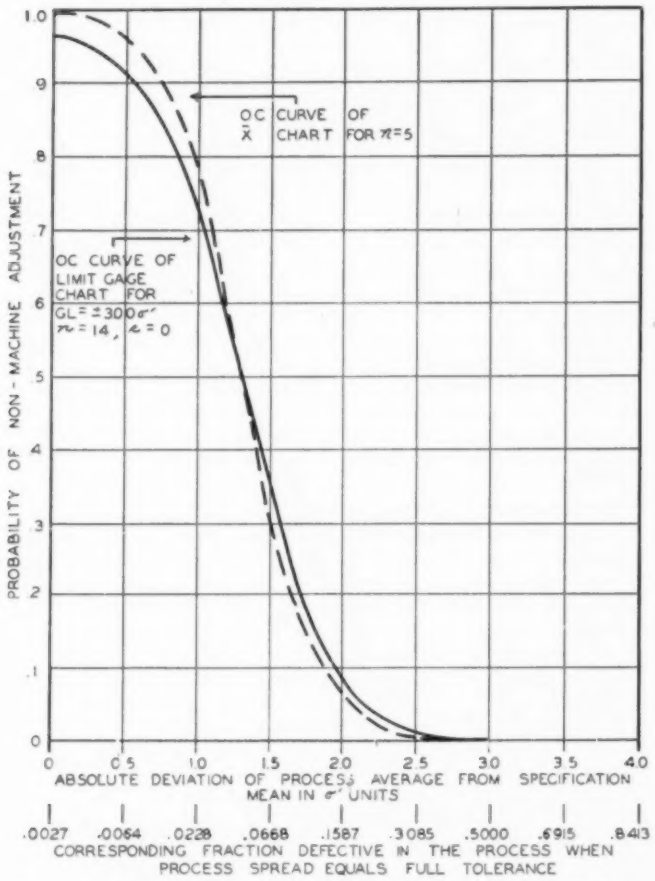

Figure 2—**Comparison of Operating Characteristic Curve for Attribute Inspection using Limit Gages at Full Process Spread (GL = ±3.00σ′, n = 14, c = 0) with that for Variables Inspection using X Chart (n = 5)**

limit is 0.0329, and the probability that three or more out of five units will fall below this limit is 0.0003. Similarly, the upper gage limit will be 0.84 standard deviations above the process mean, the probability that one unit will fall above this limit is 0.2005, and the probability that three or more out of five units will fall above this limit is 0.0583. Consequently, the probability that three or more out of five units do not fall either above or below the gage limits is $1 - (0.0003 + 0.0583) = 0.9414$. Finally, 0.0586 of the samples of five units can be expected to have at least three units either above or below the gage limits and thus call for a resetting of the machine.

The similarity between the OC curves for these two sampling plans is readily apparent from Figure 1.

Since the two operating characteristic curves match so closely, it may be concluded that the discrimination of the two sampling plans between desirable and undesirable machine settings is of the same order of magnitude. Using the limit gage procedure, slightly more unnecessary machine adjustments are called for when the process mean is within the control limits, and slightly fewer needed machine adjustments are called for when the process mean is outside the control limits. Apart from these slight discrepancies, the two sampling plans operate with virtually the same protection.

As a consequence, it may be concluded that a sampling plan which calls for a machine adjustment when three or more out of five consecutive units are either above or below ±1.34σ′ gage limits affords almost as much protection against producing defective units as does a sampling plan which calls for a machine adjustment when the average of five consecutive units measured with a dial indicator falls outside its control limits, and does so with but slightly more machine adjustment.

The particular sampling plan chosen to illustrate the application of limit gaging was largely a matter of convenience. A sample of five was chosen because this sample size is common in the application of X charts for process control. Gage limits were set at ±1.34σ′ because these are the control limits for $\bar{X}$ in samples of five. An acceptance

TABLE 4—**OC Curve Data for Attribute Inspection with Limit Gages (Alternative Gage Limits, Sample Size n = 5)**

Process Mean (in standard deviations from specification mean)	Maximum Percent Defective in Process*	Probability of Non-Machine Adjustment with c or Less Units Above or Below Gage Limits (n = 5)			
		c = 0 GL = $\pm 2.47\sigma'$ = $\pm 1.06\bar{R}'$	c = 1 GL = $\pm 1.83\sigma'$ = $\pm .79\bar{R}'$	c = 2 GL = $\pm 1.34\sigma'$ = $\pm 0.58\bar{R}'$	c = 3 GL = $\pm 0.86\sigma'$ = $\pm 0.37\bar{R}'$
0.0	0.27	.9330	.9788	.9873	.9878
0.5	0.64	.8764	.9293	.9414	.9403
1.0	2.28	.6914	.7305	.7380	.7352
1.5	6.68	.4033	.3894	.3820	.3905
2.0	15.87	.1462	.1144	.1084	.1243
2.5	30.85	.0277	.0160	.0153	.0231
3.0	50.00	.0024	.0010	.0010	.0025
3.5	69.15	.0001	.0000	.0001	.0001
4.0	84.13	.0000	.0000	.0000	.0000

*The calculation of maximum percent defective in process is based on the additional assumption that process spread equals total tolerance.

number of two units out of five above or two units out of five below gage limits was set because this acceptance number produced an operating characteristic curve which approximated that for variables inspection with a sample of five. Maintaining close parallels between the two sampling plans is highly desirable from an administrative standpoint, particularly on those machine operations where the operator is instructed to adjust his machine according to the sampling plan for limit gaging and the inspector is instructed to post an $\bar{X}$ chart according to a sampling plan for dimensional gaging.

On those machine operations where sampling inspection with limit gages is to be used as the sole basis for process control, it may be desirable to adopt different gage limits and/or different sampling plans. The choice among the various sampling procedures will then depend on: (1) how much protection against producing defective units is required, and (2) how much machine adjustment can be tolerated. To choose the appropriate sampling plan, then, the quality control manager should be familiar with the operating characteristic curves of the various sampling plans.

The usual go and no-go gage inspection provides gages with limits at least as wide as the process spread (i.e. $\pm 3.00\sigma'$ or $\pm 1.29\bar{R}'$). The quality control manager may wish to use such gages and establish a sampling procedure which will afford as much protection against producing defective units as does a sampling plan based on dimensional gaging of five consecutive units. With gage limits set at the limits of the full process spread it may be found that the appropriate sampling plan calls for a machine adjustment when one or more out of fourteen consecutive units are either above these gage limits or below them.

Table 3 gives data from which to construct the operating characteristic curve for such a plan, assuming the same conditions as stated for Table 1.

The entries in the third column of this table are obtained as illustrated herewith for the case where the process mean $\bar{X}'$ is $0.5\sigma'$ above the specification mean. Referred to this new location of $\bar{X}'$, the process spread will extend from $\bar{X}' - 3.5\sigma'$ to $\bar{X}' + 2.5\sigma'$. Using a Table of Areas under the Normal Curve, we then have $P(-3.5\sigma' < X < +2.5\sigma') = 0.99357$. The probability that all 14 sample items fall within the desired process spread, i.e. that none (c = 0) fall outside limits, is therefore $(0.99357)^{14} = 0.9137$.

The similarity between this sampling plan and a plan for variables inspection with a sample of five is readily apparent from Figure 2.

By virtue of the matching properties of the OC curves in Figure 2, it may be concluded that a sampling plan which calls for a machine adjustment when one or more of fourteen consecutive units are either above or below gage limits set at the limits of the full process spread affords almost as much protection against producing defective units as does a sampling plan which calls for a machine adjustment when the average of five consecutive units measured with a dial indicator falls outside its control limits, and does so with but slightly more machine adjustment.

To guide the quality control manager in choosing appropriate gage limits and appropriate sampling plans which will provide approximately the same discrimination as a sampling plan for variables inspection with an $\bar{X}$ chart based on samples of five, data for the operating characteristic curves of four alternative limit gage sampling plans have been calculated and are shown in Table 4. Using the integers from 0 to 3 as acceptance numbers, gage limits were calculated which would yield a 50 percent probability of machine adjustment when the process mean coincides with either control limit on an $\bar{X}$ chart for a sample of five.

In choosing an appropriate gage limit for the design of a limit gage, it is important for the quality control manager to be acquainted in detail with the condition of his machinery at the time when a machine capability study is made to calculate the standard deviation (σ') or the average range ($\bar{R}'$) for use in designing the limit gages. Once the limit gages have been built, their flexibility with

respect to changing machine capability is limited. In the event that machine capability does change, once the limit gages have been built, it may be costly to change the gage limits; but the quality control manager should be able to secure the necessary flexibility by changing the sampling plan to be used with the gage (either the sample size or the acceptance number). Anticipating the future trend of machine capability and the probable required adjustments in the sampling plan, it would be desirable that gage limits based on machine capability studies of new or recently overhauled machines be fairly narrow so that the sampling plan chosen will have a fairly tight acceptance number. Such action would permit considerable flexibility in limit gage inspection by making it possible to relax the acceptance number as the machine variation increases until an overhaul is required.

In the event that the spread of the process as revealed by machine capability studies (usually estimated as $6\sigma'$) is appreciably less than the difference between the two specification limits, it may be desirable to use modified control limits in designing the limit gages. This presents no problem which is peculiar to limit gages. For stable processes, it is merely necessary to allow each of the gage limits to deviate from the specification mean by the usual fraction of the process spread plus one half the difference between the specification tolerance and the process spread.

This article has concerned itself exclusively with the use of limit gaging for the control of stable processes (the process standard deviation, σ', is constant). Without serious sacrifice of control over quality and with the possibility of saving inspection time on some operations, limit gaging will frequently be a practical alternative to dimensional gaging with a dial indicator. However, it should be recognized that for unstable processes, or when the stability of the process is in doubt, resort to the conventional X and R chart may be justified as a diagnostic tool for distinguishing between shifts in the process level and shifts in the process spread. Even when limit gages are used with supposedly stable processes, it is desirable to make periodic machine capability studies to accept or reject the sampling plan used with the limit gages and to schedule machine overhauls.

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The Empirical Approach to the Theories of Quality Control*

THEODORE H. BROWN

Harvard University

Too often the mechanics of control chart construction or of statistical analyses assume values or formulas for which there is no intimation of their origin or validity. Surely, students and users are entitled to understand a little about the fundamentals of processes they use and deserve better treatment than the necessity of grinding through the mathematics of the theories. An approach which makes use of an empirical or laboratory method to secure approximations to the desired values may possess the attribute of simplicity and so beget understanding. At times such a method may even approximate the general plan of reasoning found in the mathematical proofs.

Four examples of the empirical approach are selected. The first is that of the relationship between the standard deviation of the means of samples and the standard deviation of the original population.

I—VERIFICATION OF THE FORMULA

$$\sigma_{\bar{x}} = \sigma'/\sqrt{n}$$

It is not necessary, but it is convenient, to base this example upon a normal frequency distribution. An approximately normal frequency polygon of 500 items is shown in Figure 1. For this distribution the value of the mean is 15.5 and that of the standard deviation is 4.972.

The first step in making use of this distribution is to draw samples from it and to record the results on the chart. For this purpose, each value corresponding to an "X" in Figure 1 was typed on a piece of paper and the paper enclosed in a gelatin capsule. A sample of 2 was drawn by taking successively two capsules from the mixture. Figure 2 shows the device used. The two values of the samples were recorded on Figure 1 by circling the appropriate two X's on the lowest line of the chart. A check mark indicates the mean value of this sample of 2. Three observations can be made about the record of several such successive samples: first, that the individuals, and hence their mean, must always be within the boundaries of the original population; second, the two items of the sample are not likely to be extreme values on one side of the distribution, so that their mean tends to concentrate about the center of Figure 1; and third, these mean values in themselves begin to form a frequency distribution, for which a standard deviation can be computed. This standard deviation is usually assigned the symbol $\sigma_{\bar{x}}$.

An experimental verification of the formula is now in order. Here, a fairly large number of samples of one size is desirable. For example, 100 samples of 2 can be drawn from the population and the mean value determined for each sample. These mean values in turn form a frequency distribution for which the standard deviation can be computed. This is, in fact, the experimental value of $\sigma_{\bar{x}}$. A similar process can be carried through for samples of other sizes.

In order to save time, instead of working with 100 samples, five samples of 2 will be drawn and their averages computed. The resulting values will be combined with the re-

*This paper was given before the Metropolitan Section of the American Society for Quality Control at Princeton on December 1, 1950. The device shown in Figure 3 and Sections III and IV of the paper were created for teaching purposes in 1932 by myself and Mr. D. H. Leavens. During the subsequent 19 years, other teaching procedures have been developed from which Sections I and II were selected because of their interest. The devices were deliberately designed with the intent to instruct rather than to entertain and were constructed from easily available materials at very low cost. Their final cost in terms of material and labor places them within reach of any teachers for whom the cost of laboratory-built precision gadgets would be prohibitive.

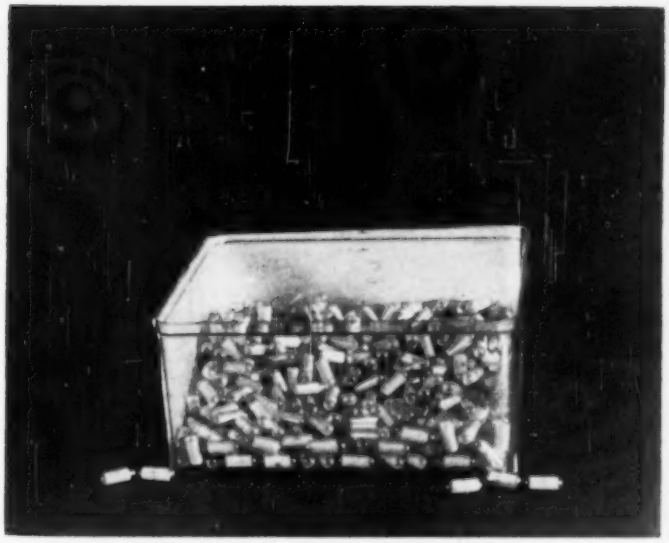

Figure 2—**Sampling Device for Experiment I**

TABLE 1—**Five Additional Drawings**

Sample Number	Sample Values		Mean	(Mean)^2	Range
1	6	18	12	144	12
2	18	11	14.5	210.25	7
3	20	19	19.5	380.25	1
4	13	17	15	225	4
5	20	16	18	324	4
	Totals		79	1,283.50	28

TABLE 2—**Summary of Experiments**

	100 Samples of		
	2	4	5
Experimental Value	3.856	2.790	2.065
Theoretical Value	3.516	2.486	2.223
Difference	0.340	0.304	0.158

sults from 95 additional samples previously drawn. The data for the five additional drawings are as shown in Table 1.

For the additional 95 samples already drawn, the sum of the mean values is 1,527. It is now necessary to add only the total (79) of the mean values of the last five samples from Table 1. This total is 1,606. The grand mean value of the 100 samples, therefore, is 16.06.

Similarly, the sum of squares of the individual 95 mean values is 25,996 and that for the five from Table 1 is 1,283.5. The grand total of the sum of squares, then, for the 100 samples is 27,279.5. From this and the value of the mean, the standard deviation* can be computed. Its value is 3.856.

Two different approaches may now be taken in the presentation. Either the theoretical formula may be assumed and the results of the experiment compared with theory, or this one experimental result may be held in abeyance until samples of other sizes have been computed, and then from a study of these empirical results the theoretical formula may be estimated. The first, which is the simpler of the two approaches, will be used here. The theoretical formula tells us that the standard deviation, which has just been computed, should be equal to the standard deviation of the original population (4.972) divided by the square root of the number in the sample ($\sqrt{2}$). This value is $4.972/\sqrt{2} = 3.516$. The experimental value noted above is 3.856. Corresponding results for 100 samples of 4 and 100 samples of 5 are shown in Table 2.

In each case it will be noted that the agreement seems to be reasonable. An appropriate significance test will show that these differences are not significant at the 5 percent level.

*The formula used is

$$\sigma = \sqrt{\frac{\Sigma X^2 - n(\bar{X})^2}{n}}$$

$$= \sqrt{\frac{27{,}279.50 - 100\,(16.06)^2}{100}}$$

II—VERIFICATION OF THE TABULAR VALUES A_2, D_3, and D_4

The values A_2, D_3, and D_4 are used to construct $\bar{X}$ and R charts through the use of the following formulas:

$$UCL = \bar{\bar{X}} + A_2\bar{R},$$

$$LCL = \bar{\bar{X}} - A_2\bar{R}.$$

For the range, the two limits are:

$$UCL = D_3\bar{R},$$

$$LCL = D_4\bar{R}.$$

The original research by Tippett in BIOMETRIKA had as its objective the discovery of the relationship between the mean range derived from a number of samples of a given size and the standard deviation of its normally distributed parent population. This immediately suggests an experimental approach.

By breaking up data for samples of 4 and 5 summarized in Table 2, there were available data for 495 samples of 2. From these the range was computed for each sample. The total value or sum of the ranges for these 495 samples of 2 is 2,708. From the five samples of 2 already drawn and shown in Table 1, the total of the ranges is 28. It follows that the sum of ranges for the 500 samples is 2,736.

Thus, the mean range of the 500 samples is 2,736/500 = 5.472. Since the ratio of this mean range to the standard deviation of the parent population is one of the values we seek, its value is 5.472/4.972 = 1.100. This is an empirical value of the quantity known as d_2 which (for samples of 2) has the value 1.128 as determined by mathematical theory. Since the $\bar{X}$ chart establishes control limits for the average of several observations, rather than for the individuals, the limits will be set at $3\sigma_{\bar{x}}$, rather than at 3σ. This means that the upper control limit will be $\overline{\bar{X}} + 3\sigma_{\bar{x}}$. Now, since the relationship between the average range and the standard deviation examined above is for σ and not for $\sigma_{\bar{x}}$, and since $\sigma_{\bar{x}} = \sigma'/\sqrt{n}$, our upper control limit will be $\overline{\bar{X}} + 3\sigma'/\sqrt{n}$.

It has already been seen that d_2 is the ratio of the mean range to σ'. In algebraic symbols, $d_2 = \bar{R}/\sigma'$, whence $\sigma' = \bar{R}/d_2$. Substituting this in the upper control limit, we have $\overline{\bar{X}} + 3\bar{R}/d_2\sqrt{n}$. The coefficient of $\bar{R}$ is A_2. From the experiment for samples of 2, we have found that the value of d_2 was 1.100. Since $\sqrt{n} = \sqrt{2} = 1.414$ for samples of 2, the empirical value of $d_2\sqrt{n}$ is 1.555, whence $A_2 = 3/1.555 = 1.93$. For samples of 2, the theoretical value of A_2 is 1.88 as determined by mathematical theory.

For the range, the two values D_3 and D_4 are found as follows: the upper control limit for ranges is $\bar{R} + 3\sigma_R$. The problem now is to find the relationship between σ_R and $\bar{R}$. For this purpose, the ranges of the 495 samples of 2 were used, plus the ranges for the additional five drawn in the experiment. The average range, R, for the 500 samples of 2 was found to be 5.472. From these same data, the value of σ_R was found to be 4.191. The ratio σ_R/R, therefore, was 0.7659.

If this ratio is assumed to hold for all samples of 2, for a new sample of 2 we will have $\sigma_R = 0.7659R$ and $3\sigma_R = 2.298R$. Hence, the upper control limit will be:

$$UCL = \bar{R} + 3\sigma_R$$
$$= R + 2.30\,R = 3.30\,R.$$

TABLE 4—**Samples of 2**

Number of Black Balls x	Probability of Drawing x	f	fx	fx^2
0	(.9) (.9) =	.81	0	0
1	(2) (.9) (.1) =	.18	.18	.18
2	(.1) (.1) =	.01	.02	.04
	Totals	1.00	.20	.22

$$\text{Arithmetic Mean} = \frac{\Sigma fx}{\Sigma f} = \frac{.20}{1.00} = .20$$

$$(\text{Standard Deviation})^2 = \frac{\Sigma fx^2}{\Sigma f} - \left(\frac{\Sigma fx}{\Sigma f}\right)^2 = \frac{.22}{1.00} - (.2)^2 = .18$$

The experimental value of D_3 is 3.30. Its true mathematical value is 3.27. Similarly, the value for the lower control limit is:

$$LCL = \bar{R} - 3\sigma_R$$
$$= \bar{R} - 2.30\,\bar{R}$$
$$= \bar{R}\,(1 - 2.30),$$

a negative number. Because a negative value is meaningless, D_4 is assigned the value zero for samples of 2.

III—STANDARD DEVIATION OF THE BINOMIAL DISTRIBUTION*

Coin Problems

The game of pitching a single coin provides a convenient medium which is analogous to the rejection or acceptance situation of an inspection department. If the coin turns up tails, this corresponds to a rejection. If it turns up heads, this represents an acceptance. Such a simple case does not carry the problem very far toward useful information. Two coins will provide a better opportunity.

If both a nickel and a dime are thrown, one of four possible situations will result. The four possibilities are:

Nickel	Dime
H	H
H	T
T	H
T	T

Since there are four equally likely ways in which the coins may fall, the chance of two heads is $\frac{1}{4}$. This means that once out of four times both coins theoretically fall heads. The probability of having a head and a tail is $\frac{2}{4}$ and that of two tails is $\frac{1}{4}$. It is to be noted that the sum of these three fractions is unity. The unit sum expresses the certainty that one or another of these individual events must occur. There can be only two heads, a head and a tail, or two tails. In the following Table 3, the results are tabulated for 1, 2, and 3 coins.

TABLE 3—**Probabilities in Tossing Coins**

No. of Coins	No. of Heads			
	0	1	2	3
1	$\frac{1}{2}$	$\frac{1}{2}$		
2	$\frac{1}{4}$	$\frac{2}{4}$	$\frac{1}{4}$	
3	$\frac{1}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{1}{8}$

The completed table suggests (1) that values for "no heads" is the chance of no heads raised to the power of the number of coins used; (2) that there seems to be a systematic arrangement of the numerators of the various fractions for a given number of coins; and (3) that these numerators can be plotted in the form of a frequency distribution. These terms are in fact the terms of the expansion of $(q + p)^n$, where q is the chance of failure, p is the chance of success, and n is the number of coins. This algebraic expression will be recognized as an application of the binomial theorem.

Sampling Experiments with Black and White Balls

A coin has only two sides. Some way is needed of getting a larger variety of experience into the denominator of the probabilities than is possible with a coin, which provides a fixed probability of success of one half. A box or urn which can be filled with varying proportions of black and white balls will do the trick.

*Taken from notes copyrighted in 1948 by Theodore H. Brown.

The process of sampling a box of white and black balls is affected by two things. One is the number of balls in the sample; the other is a change in the proportion of the black and white balls in the box. This provides an opportunity to determine the value of the standard deviation by varying first the size of the sample, or the number of balls drawn, meanwhile keeping the proportion of black and white balls in the box fixed, and then in turn varying the mixture in the box, keeping the size of the sample fixed. By this method the influence of each of the two factors on the value of the standard deviation is determined, and then by combining the information provided by these data a formula is chosen which will express the combined effect of the two elements.

Suppose that the box contains 50 black balls, representing defective pieces, and 450 white balls, representing good pieces (500 pieces in all). If a sample of one is drawn, the chance of drawing one black ball is 50/500, or 0.1, and the chance of drawing no black balls is 450/500, or 0.9. Consequently, the chance of failure is $q = 0.9$ and the chance of success is $p = 0.1$.

If a sample of 2 is drawn at random from the mixture, the chances of drawing 0, 1, or 2 black balls can be computed by the same procedure which was employed for the coins. The chance of occurrence, mean, and standard deviation are computed as in Table 4, where the symbol f here represents *relative* frequency but is used in precisely the same way as would be done with an absolute frequency in the usual frequency table.

The values as computed represent three classes of a frequency distribution with their sum equal to one. This, however, is only a numerical limitation. For example, the total number of cases, instead of being one, might be 10,000. Then the theoretical number of cases in which neither of the balls will be black is 8,100; similarly, there will be, theoretically, 1,800 cases in which one of the balls will be black and 100 cases in which both will be black. Clearly, these are the theoretical values for indefinitely large numbers of samples and finite (limited) experience will only approximate them.

In the computation for samples of 2, the proportion of defective pieces, represented by the black balls, was maintained constant and only the size of the sample was altered. Similar computations can be made for samples of larger size. The results are written in the following table, where only the square of the standard deviation has been used.

TABLE 5—Samples from Same Universe

Sample of Size n	Average	σ^2
2	.20	.18
4	.40	.36
6	.60	.54
8	.80	.72
10	1.00	.90
12	1.20	1.08
14	1.40	1.26
16	1.60	1.44

What is now wanted from the above theoretical data is an appraisal of how the square of standard deviation varies with the number of items in the sample. Examination of the table shows that the ratio of σ^2 to n is constant. This is not an accident; it will always be true, provided the proportions of black and white balls are kept constant in the mixture.

We are now ready to appraise the effect of varying the proportion of defectives (black balls) in the mixture. For this, the size of the sample will be kept fixed and the proportion of black and white balls altered. The simplest sample size to use for a minimum of computation is 2. In the following Table 6 the sample size of 2 is used throughout. This size of sample has already been used in the computation of the average and the square of the standard deviation for a mixture of 10% black and 90% white balls. The results for several other mixtures are given in the table. In addition, the final column takes out the size of the sample of 2, which has been found above to bear a direct relationship to σ^2.

Remembering that p stands for the percent of black balls and q for that of white balls, the problem becomes: first, make a judgment as to how the numbers in the last column can be obtained from the figures of percentage of black and white; and second, write a formula in terms of p and q. Proceeding in this manner, we are led to write $\sigma^2/2 = pq$, whence $\sigma = \sqrt{2pq}$. Now, since 2 is the size of the sample for this case, in the general case where n is the size of the sample, we will have $\sigma^2/n = pq$, whence $\sigma = \sqrt{npq} = \sqrt{np\,(1-p)}$, since $p + q = 1$.

IV—t—TEST*

The fourth problem is that of obtaining an understanding of the background for the t-test. The form of the t-test which has been selected is that which tests an observed sample mean $\bar{X}$ to see whether the observed $\bar{X}$ could reasonably have been a member of a population of averages which has the standard $\bar{X}'$ as its mean. The variable t may be defined by the following equation:

$$t = \frac{\bar{X} - \bar{X}'}{\sigma_{\bar{x}}}$$

Here $\sigma_{\bar{x}}$ represents the standard deviation of means of samples.

This definition of t is a natural one. Consider first the numerator. The question is whether the mean of a sample, $\bar{X}$, differs so much from the standard, $\bar{X}'$, that the two must be judged to have originated in two different populations. The denominator is naturally a standard deviation because its use converts the differ-

*Data taken from notes copyrighted in 1948 by the President and Fellows of Harvard College.

TABLE 6—Samples of 2

Black Balls Percent	White Balls Percent	Average	σ^2	$\sigma^2/n = \sigma^2/2$
10	90	.20	.18	.09
20	80	.40	.32	.16
30	70	.60	.42	.21
40	60	.80	.48	.24
50	50	1.00	.50	.25

ence expressed by the numerator into standard units, which can be related to a known frequency distribution. Without this conversion into standard units, the significance of the t-test would be lost.

Now it happens that at times values of t can occur easily by chance. This arises when $\bar{X}$ and $\bar{X}'$ both belong to the same population. The question is how to design an experiment which will provide values of t and which will reflect the frequency of the various chances. The distribution of such values should provide an approximation to the basic mathematical distribution. A symmetrical distribution which is not too unlike a normal one is shown in Table 7. $\bar{X}'$, in the formula for t, is chosen as the actual value of the mean of this distribution. Samples are then drawn and the values of t are computed. Because $\bar{X}'$ and all samples are drawn from the one population, the resulting t-values must be caused only by chance.

TABLE 7—**Distribution of Bead Population**

Code Color	Value X	Frequency f	fX
R	1	20	20
O	2	80	160
Y	3	120	360
G	4	80	320
B	5	20	100
Mean = 3 = $\bar{X}'$	Totals	320	960

The device used to draw the samples is shown in Figure 3. Because this device makes use of beads which are difficult to identify by number, it is a little easier to code the varying magnitudes in terms of color. Table 7 shows this coding, in which R stands for red, and so on. The box is so constructed that internal baffles ensure a thorough mixing of the beads as the box is rotated on the horizontal axis. The box can then be tipped so that a sample of 10 appears in the stem.

As in the previous problems, the routine time of drawing many samples is reduced to a manageable form by including samples for which values have already been computed. In this case, the values for five samples are first determined and their results then added to 95 samples for which t-values have been computed.

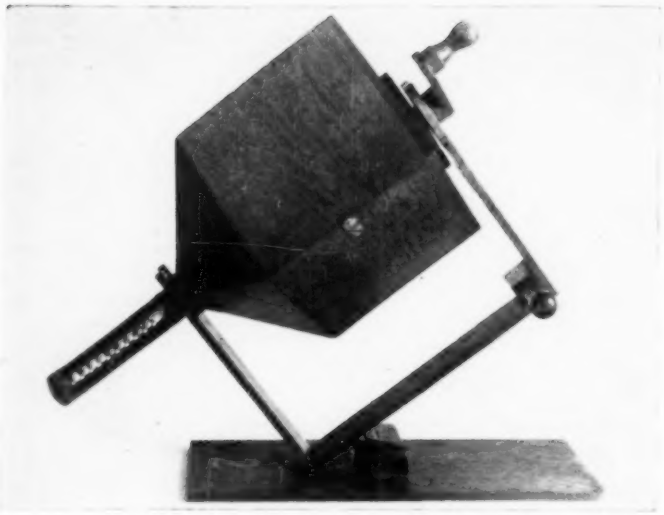

Figure 3—**Sampling Device for Experiment IV**

Table 8 shows the data for the five samples. Table 9 presents the values previously computed for 95 samples of 10 and adds the values for the five samples. This table is in the form of a frequency distribution of 100 items. Theory gives the mathematically calculated values of t for 9 degrees of freedom in percentage form, which can be compared immediately with the experimental frequencies of 100 samples.

The distribution of experimental values contains some obvious discrepancies. The distribution also possesses only five classes. Nevertheless, an appropriate chi-square test will show that these differences are not significant at the 5 percent level. The obvious fact now is that in any actual case the value of t has got to be sufficiently large so that a similar value would be extremely unlikely to occur in an experiment such as that which has just been described. In such an event, $\bar{X}$ and $\bar{X}'$ probably do not arise from the same population.

TABLE 8—**Data for Five Samples of 10**

Sample Number	Mean $\bar{X}$	σ	$\bar{X} - \bar{X}'$	t
1	3.4	1.173	+0.4	+1.078
2	3.3	1.059	+0.3	+0.896
3	3.1	1.449	+0.1	+0.218
4	3.0	1.333	0.0	0.000
5	2.7	0.823	−0.3	−1.153

TABLE 9—**Summary Data**

t-Value	Frequency for 95 Samples	Frequency for 5 Samples	Total Frequency for 100 Samples	Mathematical Distribution (Percent)
−3.749 to −2.250	5	0	5	2
−2.249 to −0.750	20	1	21	21
−0.749 to +0.749	54	2	56	54
+0.750 to +2.249	15	2	17	21
+2.250 to +3.749	1	0	1	2

Analysis of Machine vs. Shift Performance Data

Ellis R. Ott
Rutgers University

It is common procedure in many plants to record the performance data of different machines, shifts, and operators. A technique of *combining* and analyzing these data from the different possible sources is illustrated in the following paragraphs. The method is a very powerful one and is worth the consideration of quality control men.

We have selected some data from a very interesting article by J. Stuart Zahniser and D. Lehman* as the central data to illustrate different methods of analysis. These data relate to the performance of five different presses (machines) over three different shifts. The data, recorded in Table 1, indicate both the number of times each press was checked and the number of times its performance was so unsatisfactory that the press had to be shut down for repairs; this latter item is indicated by "number of shut-downs". We quote from the Zahniser-Lehman article:

"As the product comes from these presses, there are 57 separate characteristics that require an inspector's audit. It takes two or three minutes to complete the examination of a single piece. Yet the combined production from these presses reaches more than a million a day. To cover this job with a series of charts for variables would require a minimum of 15 inspectors, . . . (We) use a chart that we call a "shut-down" chart. The shut-down chart is a p-chart on which each point gives the percentage of checks resulting in shut-downs for a given press on a given shift during a two-week period. On this chart, n represents the number of times the press has been checked on this shift during the particular period". . . .

"Typical data for a shut-down chart are shown in Table 1."

* "Quality Control at Talon, Incorporated", *Industrial Quality Control*, March, 1951, pp. 32-36.

Send your "Practical Aid" contribution to:
Dr. Ellis R. Ott
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New Brunswick, N. J.

"The percentage of checks resulting in shut-downs in the department = 10%. The average number of checks per press per shift = 750/15 = 50. Press #2 on C-shift is in this case out of control at 25.4% and we look for the assignable cause". (See Figure 1).

TABLE 1—**Talon's Press-Shift Performance Record**

Press Number	Shift	Number of times checked	Number of shut-downs	% of checks resulting in shut-downs
1	A	50	2	4.0
	B	55	7	12.7
	C	40	4	10.0
2	A	45	3	6.7
	B	55	3	5.5
	C	55	14	25.4
3	A	40	0	0
	B	35	3	8.6
	C	45	0	0
4	A	50	6	12.0
	B	55	9	16.4
	C	60	11	18.3
5	A	60	4	6.7
	B	45	3	6.7
	C	60	6	10.0

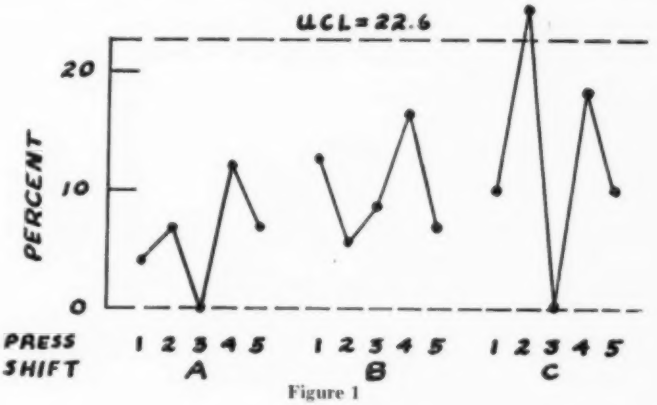

Figure 1

"The speed of the presses has been increased by 32% since control charts were first applied. Nevertheless, we find that the percentage of audits which result in shut-down has been cut squarely in half. Obviously the quality of product coming from them is vastly better than it was three years ago, even though our charts measure quality only indirectly."

The merit of records of this kind *which are also charted* for a continuing history is thus clearly demonstrated. Since the authors did not indicate their methods of looking for the assignable causes either of definitely inferior or superior performance, we have taken this opportunity to present three different methods of analyzing these particular data. The methods are applicable to a wide variety of manufacturing situations.

Analysis 1

There are 15 individual points which can be plotted, if desired, on an ordinary p-chart. The average percent of shutdowns is

$$75/750 = .10 = 10\%.$$

Although sample sizes vary from a low of 35 to a high of 60, control limits can be set "tentatively" corresponding to n = 50 which is the average sample size. The limits are:

UCL = 22.6% and LCL = 0.

From Figure 1, it is apparent that the percent of shutdowns of Press #2, Shift C, exceeds the UCL, indicating the presence of an assignable cause. It might be noted that n = 55 corresponds to this point; this has the effect of narrowing slightly, for this one point, the control limits which were computed on the basis of n = 50.

Conclusion: This analysis indicates the presence of at least one assignable cause. Whether it is the press or the shift or both which need corrective action does not appear from this analysis.

Two things should be noted here: (1) this much data should contain more conclusions than have been so far indicated in our analysis, and (2) data of this type may frequently contain evidence of peculiar behavior *even though no individual point is outside control limits.*

Analysis 2

Let us consider an extension of our Analysis by arranging our data in the form shown in Table 2.

TABLE 2—**Table of Shut-Downs (Overall = 10%)**

	PRESS					
SHIFT	1	2	3	4	5	f_i Total
A	2 n = 50	3 45	0 40	6 50	4 60	15 245
B	7 55	3 55	3 35	9 55	3 45	25 245
C	4 40	14 55	0 45	11 60	6 60	35 260
TOTAL	13 145	20 155	3 120	26 165	13 165	

In Table 2, we have indicated the original data displayed in a form which often allows a more powerful analysis. (The numbers in the lower right-hand corner refer to the number of checks made.) We have indicated, at the right, the total number of shutdowns extended over each shift to include all five presses. Peculiarities will often be indicated from combined groupings, of this type, which are not apparent otherwise.

The percent shutdowns on Presses #1 through #5, respectively, are:

9.0%, 12.9%, 2.5%, 15.7%, and 7.9%.

The corresponding sample sizes are, respectively:

145, 155, 120, 165, and 165.

We can graph the above percents and set tentative control limits on a new p-chart corresponding to the average sample size, n = 150. The p-chart is shown in Figure 2.

Press Performance: The percent of shutdowns for Press #3 is outside 2-sigma limits and is very close to the 3-sigma limit. (Actually, n = 120 for Press #3, and this has the effect of widening the limits slightly.) What do we conclude? If we had additional data in the files, we should examine it to see if our suspicion that Press #3 is exceptionally good is substantiated during previous operation. Also, we should repeat this analysis at the next opportunity. This assumes that we have no reason to believe that Press #3 contains any particular adjustments or factors which predict that its performance should be better than the other machines. We may be reasonably confident that, in some way, the data from Press #3 is different from the general average of 10%. If the press contains some feature which is exceptionally favorable, we want to discover what it is, and incorporate it into the operation of the other presses if that is economically feasible.

Similarly, we should check with any other available data to see if Press #4 indicates habitual poor performance. If it does, we will attempt to identify and eliminate the unfavorable feature. We have not given definite proof that Press #4 is bad (compared to the others)—but there is a suspicion that its behavior is different.

Shift Performance: The percent shutdowns on Shifts A, B, and C are, respectively:

6.1%, 10.2%, 13.4%.

Sample sizes are:

n = 245, 245, 260.

A graph of these data is shown in Figure 3, with the control limits. Although no individual point lies outside 3-sigma limits, the presence of

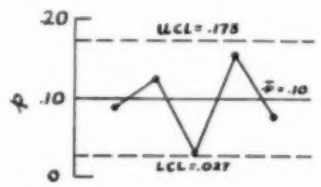

Figure 2

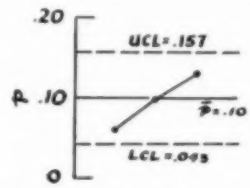

Figure 3

two points very close to 2-sigma limits may be enough to cause us to ask, "Is there anything in our plant experience with this process to make us think that Shift A may be above average and Shift C below average in performance?" The straightforward control chart analysis does not give quite enough evidence, by itself, to argue that one shift is either better or worse, fundamentally, than another. In many situations, however, it will indicate clearly a difference which Analysis 1 will not show. Also it points definitely to the *reason* for the different performance.

Analysis 3

Although there may be no single point outside control chart limits to indicate fundamental differences in behavior, it may still be true that the overall pattern of *variation* indicates that the variations observed are probably not chance variations from a process operating at a fixed level. The chi-square (χ^2) technique* is a measure of the *overall variability* of a set of data to indicate whether the variability is unusual. Some quality control men may be interested in this analysis—it is often unnecessary but it is worth while to learn.

Let us extend the right side of Table 2 by adding the two columns labeled F_i and $(f_i - F_i)^2/F_i$.

TABLE 3—Differences in Shifts (Chi-Square)

Shift	f_i Total	F_i (10%)	$\frac{(f_i - F_i)^2}{F_i}$
A	15 245	24.5	3.7
B	25 245	24.5	0.0
C	35 260	26.0	3.1
		Total	$\chi^2 = 6.8$

The computed value of χ^2 is 6.8 on the basis that the theoretical expected percent (F_i) in each of the three categories is 10%, which is the overall percent of shutdowns. To determine whether a value of χ^2 as large as 6.8 from three groups of data is unusual, (i.e., there are 3-1 = 2 "degrees of freedom") we consult tables which have been prepared.

* See *Introduction to Statistical Analysis*, by Dixon and Massey, McGraw-Hill Book Company, Inc., pp. 184-189.

TABLE 4—**Differences in Presses**

Press	Observed f_i	Theoretical F_i (10%)	$\frac{(f_i - F_i)^2}{F_i}$
#1	13	14.5	.15
#2	20	15.5	1.31
#3	3	12.0	6.75
#4	26	16.5	5.47
#5	13	16.5	.75
		Total	$\chi^2 = 14.43$ (df = 4)

In Table 6a, p. 308 (Dixon and Massey, *loc. cit.*,), or from similar tables, the critical values are read as follows, corresponding to our 2 degrees of freedom (d.f.):

5.99 at 95%
7.38 at 97.5% (2 d.f.)

Our value, $\chi^2 = 6.8$, lies between these two values, and indicates that the probability of getting a smaller value than obtained here, on the basis of chance, is approximately 96%. Thus, on the basis of this statistical analysis, there is about one chance in twenty-five (4%) that this is just chance variation. We may therefore suspect that there is a real difference between shifts here, i.e., more of a difference than we would usually expect to find due to chance only.

Similarly, we may compute χ^2 for possible effect of presses, as shown in Table 4.

The critical values (Table 6a) are as follows:

13.28 99%
14.86 99.5% (d.f. = 4)

In other words, there is even more evidence that there is a genuine difference between machines than there is between shifts. This is a substantiation of the suspicion that we drew from the control chart analysis.

Conclusion

In analyzing data from several groups of machines, operators, shifts, processes, batches, etc., it is frequently possible to draw more important conclusions if we combine the data as in Analysis 2 than if we examine only the individual records of performance. If there is still doubt about the analysis, it will sometimes be in order to use the "fancier" analysis of the chi-square method, such as in Analysis 3.

The importance of being able to "point a finger" at the reason for any difference in performance, as provided either by Analysis 2 or 3, is apparent.

The method of combining data validly from several different sources can frequently be applied to existing data from three or more different sources. Consequently, the technique becomes important to the development and research man as well as to the production man.

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Business Manager

(SEAL)

FRANK A. BOETTELIN
Notary Public

(My commission expires March 23, 1952.)

Sworn to and subscribed before me this 21st day of September, 1951.

Problems Department

PAUL C. CLIFFORD, Editor

Problems for solution, and correspondence concerning material published in this department, should be addressed to
PAUL C. CLIFFORD
39 Norman Rd.
Montclair, N. J.

COME ON IN, THE WATER'S FINE

I am pleased to report that one half of this job of being problems editor is a cinch. That part is getting the problems. The job of getting discussion on these problems is progressing more slowly, but there *is* progress. Send in your problems, as well as your reaction to those already stated. Eventually we will get some sort of answer.

WHERE DO YOU WORK-A, JOHN?

One thing we are in doubt about is the question of credit lines for problems. Should we list the name and affiliation of the person who submits the problem? Seems to me that this helps to insure that the problems are real. Otherwise I could be just making them up, than which nothing is easier.

On the other hand, some companies may not wish to admit that there are any problems which they haven't solved, or they may wonder what they are paying you for, if you don't know all the answers. What is your reaction?

SLIGHT PAUSE FOR STATION IDENTIFICATION

We have deliberately missed the past two issues, getting reactions to the first problem page. We expect to appear on schedule from here on with new problems, suggested solutions, or progress reports.

Project 1—Progress Reports

This suggested project, concerning limit gauging and test of increased severity, brought several interesting replies.

Frank Satterthwaite of the Chemical Department, General Electric Company, sent in a copy of "Quality Control by Limit Gauging," prepared by the Advisory Service on Quality Control, British Ministry of Supply, in October, 1944. The essence of this article is available in Edward Schrock's "Quality Control and Statistical Methods."

Ellis Ott of Rutgers University pointed out a discussion in Dudding and Jennett's "Quality Control Chart Techniques When Manufacturing to a Specification."

John Tukey of Princeton recommended an article on the theoretical foundations by W. L. Stevens: "Control by Gauging," Journal of the Royal Statistical Society, Series B, Vol. 10, No. 1, 1948.

William Gore of DuPont in Wilmington sent in a first draft on "Tests of Increased Severity" which was the result of some original work that he did four or five years ago.

On the industrial side, Jack Meroz and Ed McCauley sent in a "Band Chart" they have developed for use in the Timken-Detroit Axle Company. August Mundel reported some experiments using control gauges at Sonotone. Paul Dickerson of Westinghouse reports similar experiments.

It appears that this first project was quite a big one. The results so far are quite confusing. This seems to be due to different assumptions, some of which are unstated. Some of the solutions attempt to control slippage of the mean, assuming control of the variability. Others depend on the normality of the distribution, while still others are using control gauges in place of "modified" control charts.

This suggests that what is needed is a long expository article surveying the entire field, examining the assumptions on which each procedure is based, and comparing the efficiency of different solutions. Your Editor has asked Thomas Budne of Squibb (and Rutgers University) to help him prepare such an article. We would appreciate hearing of other experiences with control gauging so that this survey will be as comprehensive as possible.

Problem 2

Suggested by David N. Collins, Georgia Section

Given two small equal samples of unpaired data, the statistic computed is $1/(\bar{X}_1 - \bar{X}_2)$. How should the variance of this statistic be estimated? This problem occurs in calibration of an analytical balance, but the reciprocal of this difference is used in the determination of an unknown weight.

Problem 3

Suggested by Paul A. Noakes, Indianapolis Section

In attempting to evaluate the quality level of each of a group of assembly departments, the use of demerits has been attempted. Due to inherent difficulties of certain assemblies, differences in economic value as well as variability in experience with different assemblies, this procedure has not been too satisfactory. What other procedures have been followed in attempting to evaluate department performance?

Problem 4

Suggested by Thomas A. Budne, Metropolitan Section

In using probability paper to estimate the mean and standard deviation of a sample, what procedure should be followed in drawing the line which gives this estimate? We are "fitting" a line to a set of points. However, the usual technique of least squares cannot be followed. The usual procedure is to fit the line by eye, which is subject to all the errors of any "eye" test.

Comment on Problem 4

I had previously discussed this problem with Enoch Ferrell of Bell Telephone Laboratories. He has suggested several interesting techniques which tend to minimize the error, in estimating $\bar{X}$ and σ in a sample from a normal distribution. One of the most interesting has to do with the use of normal probability paper in making estimates from non-normal distributions. I shall report on this discussion sometime in the future, but in the meantime I am interested in discovering what other techniques may have been developed.

How do you like the "heft" of this January issue?
We're starting out with
"52 in '52"
and a separate, heavier cover.
M.E.W.

Book Reviews

A. C. Cohen, Jr., *Editor*

ELEMENTARY PRINCIPLES OF STATISTICS

A. C. Rosander, D. Van Nostrand Company, New York, 1951. x + 693 pp. $6.00. Review by Paul R. Rider, Professor of Mathematics, Washington University, St. Louis, Missouri and Mathematical and Statistical Adviser to Flight Research Laboratory, Wright-Patterson Air Force Base, Dayton, Ohio.

This book treats in an elementary fashion the usual topics to be found in an up-to-date book on statistical methods. In addition, it takes up certain topics sometimes omitted in such books and discusses in detail other topics briefly considered by them. For example, it is very gratifying to see a rather full discussion of the important subject of sampling. Some of the phases of sampling that are treated are: sampling from a finite population, nonrandom or judgment selection, such as quota sampling, stratified sampling (to which an entire chapter is devoted), serial selection, and other types of restricted sampling, sequential sampling, and sample size. In other words, considerable attention is given to the obtaining of samples as well as the analysis of the results.

The principal criticism of the book is that the author's style lacks the precision which is necessary in a book of this character. Many of the statements and definitions are confused, or even erroneous. Several examples of what is meant will be given.

On page 102 the following sentence is found: "The probability of occurrence of a specified range of a variate which has a fixed population distribution is equal to the area under the proportions distribution between the specified limits." What is meant is that the probability that a variate from a fixed population will lie between two specified limits is equal to the area under the frequency curve between the two limits (it being understood that the total area under this curve is unity).

"Error" is defined on page 210 as "the deviation of an observed or obtained value of x from a true or expected value X". In the next paragraph the three main classes of error are stated to be errors of measurement, errors of estimation, and errors of inference. An error of inference would hardly come under the definition.

Correspondence and suggestions concerning book reviews should be sent to:
Professor A. C. Cohen, Jr.
Department of Mathematics
University of Georgia
Athens, Ga.

In Chapter 24 on Statistical Inference there is considerable confusion regarding the meaning of hypothesis. A hypothesis is an assumption, not an inference, and hardly a proposition as the author states. It is certainly not put in interrogative form although he gives as an example of a hypothesis "the question—Is cotton cord or rayon cord best for synthetic rubber tires?"

Several typographical and other errors were noted, of which the following possibly warrant mention:

Page 87—In the last formula, the coefficient N_1 is missing from the x_1 in parentheses.

Page 88—In the first formula, the coefficient N_1 is missing from the x_1 in parentheses.

Pages 88-90—In the formulas the upper limit of summation should be k instead of N.

Page 195—Mathematically speaking, the normal probability function is a transcendental function, not an algebraic function.

Page 203—The normal curve in Figure 25 is badly drawn.

Page 232, line 5—The words "when the size of the sample n is equal to N, the size of the population" should be deleted, since the normal population is an infinite population.

Page 461—References. "Camp, H. H." should be "Camp, B. H."

Page 500—lines 19, 21, 23. The hyphen in "K—estimated" should be deleted.

Page 502—lines 3, 6, 11. The hyphen in "K—sets" and "m—ranks" should be deleted.

CONFIDENCE LIMITS FOR THE HYPERGEOMETRIC DISTRIBUTION

J. H. Chung and D. B. DeLury; University of Toronto Press, 1950. xiii + 70 charts. Review by S. Lee Crump, Atomic Energy Project, School of Medicine and Dentistry, University of Rochester, Rochester, N.Y.

This volume fills the need for a useable method of obtaining accurate confidence limits for the proportion defective in cases where the sample includes an appreciable fraction (one in twenty or more) of a finite number of items. Charts are provided for determining 90%, 95%, or 99% two-tailed confidence intervals for the proportion (or number) of defectives in lots of size 10,000, 2,500, or 500 at sampling rates of 5%, 10%, 20%, . . . , 90%. Brief introductory notes give the method of construction and directions for use of the charts. Adequate instructions for interpolation are included. Unfortunately the method of construction leads to lower limits which are not those ordinarily defined. The convenience of the charts is thereby partially destroyed. However, a simple compensating correction in entering the charts is all that is required for obtaining the conventional limits. This is described in a correction inserted after printing the book.

A spot check showed no errors beyond the limits indicated by the authors. Some of the charts in my copy are out of logical order.

Rochester Society for Quality Control
Annual Quality Control Clinic
February 19, 1952

For program details, write to
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Rochester 4, New York

Management's Corner

J. M. JURAN, Editor

Correspondence is invited on potential contributions or problems appropriate for discussion in this department. Address your suggestions to:
J. M. JURAN
195 Beech Street
Tuckahoe, N.Y.

ORGANIZING FOR QUALITY ON THE FACTORY FLOOR

We often talk of organization for quality control. Usually this is on the basis of "top-level" organization. (To whom should the quality control department report, and the like.) But seldom do we discuss the equally important problems of organization at the bottom. Yet lack of adequate organization on the factory floor is frequently a contributing factor to poor quality and high cost.

There are two management tools which can be of great aid in organizing for quality on the factory floor. One of these tools is the table of delegation; the other is the detailed description of how the delegated responsibilities are to be carried out.

A List of Factory Floor Quality Tasks

The cycle of production includes a series of acts which are directly related to quality of product. These acts include:

(1) *Set up acceptance.* This is the determination of whether a process (machine, assembly line, etc.) just set up is in fact able to deliver acceptable product. This determination usually[1] decides whether the process should commence production or not.

(2) *Running acceptance.* This is the determination of whether a process is continuing to deliver acceptable product. This determination usually decides whether the process should continue producing or should be shut down.[2]

(3) *Lot acceptance.* This is the determination of whether the lot of product (made during the interval between two successive process acceptance checks) may be accepted for use in the next operation (or by the customer), or should be sorted, junked, repaired, etc.

(4) *Piece acceptance.* This is the job of sorting questionable lots to separate acceptable pieces from non-acceptable.[3]

(5) *Recording of data for process control.* This is the job of recording enough data to provide the information needed for regulation of the process so as to achieve defect prevention.

(6) *Analysis of process control data.* This is the job of summarizing, computing, and interpreting the data collected for process control.

(7) *Action on process control data.* This is the job of stopping and/or revising the process as dictated by the control data.[4]

List of Delegants

The foregoing list is not quite complete, but it will do. The question now is, "Who is to do each of these seven essential jobs of quality control at the factory floor?" This leads to a consideration of who are the people on the factory floor available to do these jobs? The roll call of men on the factory floor usually includes:

The operator.
The set-up man.
The "patrol," "roving," or "machine" inspector.
The "bench" or "detail" inspector.
The foreman.[5]

A Table of Delegation

The problem is now to delegate the 7 jobs to these 5 men. A useful way to approach this is to prepare a two-dimensional table of delegation. Table 1 reflects the situation prevailing in the machine departments of a well-known Midwestern company.[6]

There is great value in the discipline of reducing to writing the "understanding" of "whose job it is to do what." On more than one occasion I have asked every production supervisor in a plant to fill out, anonymously, *his* understanding of how these 7 quality jobs are delegated. The resultant papers have invariably been illuminating, and have provided the basis for securing real agreement to replace the foggy "understandings."

The Need for Written Procedures

So much for the table of delegation. To write it out clears up the question of *who* is to do which job. But it does not make plain *how* the job is to be done. Here the cardinal choice is whether the management should:

(a) Let the man do the job in accordance with the dictates of his own judgment.

(b) Establish a procedure he should follow before he can make the decision.

Here again it is well to face the issue squarely. Management must decide by deliberate act rather than by default whether the men on the floor should be guided by procedures or not.

There is much inadequacy in the procedures presently used by industry for making these decisions. For many plants it has become desirable that there be spelled out:

(1) The specification, i.e., what characteristics must be measured.

1. Sometimes it may be necessary, for reasons of urgency, to run a process which delivers a degree of non-conforming product.

2. Set-up acceptance and running acceptance are two aspects of "process acceptance." Some of the terminology here is borrowed from L. A. Seder's chapter in Quality Control Handbook (J. M. Juran, McGraw-Hill Book Co., 1951).

3. Lot acceptance and piece acceptance are two aspects of product acceptance.

4. Recording, analysis, and action constitute the essential aspects of process control.

5. Foreman is used here in a generic sense to mean the supervisor on the factory floor.

6. This table of delegation is shown merely as a sample, and not as an example of sound delegation. What is sound delegation depends on the character of the product, the capability of the process, the skill of the personnel, and still other factors.

TABLE 1

	PROCESS ACCEPTANCE		PRODUCT ACCEPTANCE		PROCESS CONTROL		
	SET-UP	RUNNING	LOT BY LOT	PIECE BY PIECE	RECORDING	ANALYSIS	ACTION
OPERATOR		X			X		X
SET-UP MAN	X				X		X
PATROL INSP		X	X		X	X	
BENCH INSP				X			
FOREMAN							X

(2) The sampling plan, i.e., how many measurements should be made, how often the measurements should be made, etc.

(3) The acceptance criterion, i.e., what should be the relationship of the measurements to the specification limits (or control limits if appropriate).

Heretofore such procedures have been devoted mainly to problems in product acceptance. Today's problems of mass production of precision goods require that decisions on process acceptance and on process control likewise be based on agreed-upon procedures as an essential supplement to the experience of the men on the factory floor.

Wherever organization for quality control is well worked out on the factory floor, there we seldom find the need for questioning the organization at the top.

Bibliography

JOSEPH MOVSHIN, Editor

Assisted by the Editorial Committee, St. Louis Section, ASQC

On matters concerning the Bibliography Department, send correspondence, suggestions, and contributions to: Mr. Joseph Movshin, 9220 Old Bonhomme Road, St. Louis 24, Mo.

APPLICATION—CHEMICAL INDUSTRY

MICRODETERMINATION OF CARBON AND HYDROGEN, C. L. Ogg, C. O. Willits, Constantine Ricciuti, & J. A. Connelly, Eastern Regional Research Laboratory, Philadelphia, Pa.
(Analytical Chemistry, v. 23, n. 6, June 1951)

A collaborative study of the microdetermination of carbon and hydrogen was conducted to find an accurate method suitable for adoption by the Association of Official Agricultural Chemists. The results were analyzed statistically to determine the effects of different variables on the accuracy and precision of the method. This statistical analysis indicated that certain details of the carbon and hydrogen method should be eliminated, and that a more simplified procedure than is often used should produce more accurate and equally precise results.

FURTHER EXAMINATION OF REPRODUCIBILITY IN CHEMICAL ANALYSIS, J. O. Lay, A.R.I.C.

(Journal of the Iron and Steel Institute, v. 167, n. 1, January 1951)

A statistical comparison of results obtained in the evolution of standard chemical and absorptiometric analytical methods for manganese indicates the relationship between standard deviation and reproducibility of results and the contribution of certain factors to the variations found.

APPLICATION—METAL WORKING

STATISTICAL QUALITY CONTROL OF METALWORKING OPERATIONS, Lester F. Spencer, Chief Metallurgist, Landers, Frary & Clark.
(Steel Processing; Part I, v. 37, n. 7, July 1951, p. 336)

The control of quality and inspection has become an important necessity in industry. The statistical methods of quality control are the latest tools in this important work. This article, after a background review of inspection, discusses sampling procedures, the Dodge-Romig Sampling Plans, and the Ordnance Plans.
(Part II, v. 37, n. 8, August 1951, p. 382)

The frequency distribution and $\bar{X}$ & R chart are discussed in detail. Illustrated with a number of distributions and charts.

APPLICATION—METALLURGICAL INDUSTRY

STATISTICAL ANALYSIS OF BLAST FURNACE PRODUCTION DATA, D. S. Leckie, Quality Control Engineer, Republic Steel Corporation, Cleveland, Ohio.
(Journal of Metals, June 1951, p. 443)

There are three separate and distinct phases or problems associated with these studies, the first being the selection and suitable tabulation of the data (must be factual data). Second is the systematizing and streamlining of the calculations. Third is the interpretation of results. Fully automatic calculating machines help systematize the entire operation. Mechanized mathematics, however, cannot replace the experience, skill, and know-how of the operator.

STATISTICAL QUALITY CONTROL, H. H. Johnson, National Malleable & Steel Castings Co., Sharon, Pa.
(Foundry, v. 79, n. 7, July 1951, p. 92)

This is a lengthy, detailed article on the use of control charts in a foundry. The use of the average and range chart and its meaning in terms of the process frequency distribution is given with detailed examples of the construction of the chart.

Tangible benefits resulting from the use of these charts are noted.

QUALITY CONTROL CHARTS BOOST FORGE-SHOP PERFORMANCE, R. D. Long, Chief Inspector, Fort Wayne Works, International Harvester Co.
(American Machinist, v. 95, n. 31, Oct. 15, 1951, p. 154)

Mr. Long attributes longer die life, lower forging costs, and higher quality to the use of control charts in a forge shop. An average and range chart on forging weights is shown. This chart helped improve die life. Another chart for recording defects during sampling checks is also given.

APPLICATION—MISCELLANEOUS

PREDICTION & PRODUCTION OF SPRINGS BY STATISTICAL QUALITY CONTROL, Erwin E. Schiesel, Technical Di-

rector, The Mattuck Mfg. Co., Waterbury, Conn.
(Wire & Wire Products, v. 26, n. 5, May 1951, p. 385)

The author states that his company has produced over 7 million springs for the U.S. Government. These were accepted without 100% inspection because of the use of statistical methods of control. Frequency distributions and average and range charts are used and their application to such operations as the setting of specifications, testing, heat treatment, and plating are described.

CASE STUDY IN THE APPLICATION OF INDUSTRIAL STATISTICS TO PAPER MAKING, Charles A. Bicking & Richard T. Trelfa.
(Tappi, v. 34, n. 8, August 1951, p. 370)

An extensive article describing 5 case studies of actual applications of industrial statistics to paper making.
The case studies given are as follows:

I. Control of a paper machine to reduce variation in measurements across the machine as well as in the machine direction.
II. Analyze and portray changes in quality on processing conditions as a guide for better control.
III. Comparison of testers to determine their ability to reproduce their own results and check those of others. Also to determine the number of tests required to check within certain limits.
IV. Reduction in the number of errors made by paper sorters.
V. Investigation of paper testing techniques to identify factors which may be improved.

QUALITY CONTROL IN THE MANUFACTURE OF CERAMIC DIELETRICS, C. T. Raymo, American Lava Corporation, Chattanooga, Tenn.
(Ceramic Age, v. 57, n. 5, May 1951, p. 17)

The maintenance of uniform quality on a satisfactory level has been a most difficult phase of the ceramic business. The application of the tools of statistical quality control has shown considerable progress towards the solution of the quality problem. Several physical, electrical, and manufacturing process variables are listed which lend themselves to this control. Sampling and frequency distribution as well as control charts are mentioned.

ENGINEERING & EXPERIMENTS

MODERN STATISTICAL SCIENCE AND ITS FUNCTION IN EDUCATIONAL AND PSYCHOLOGICAL RESEARCH, Palmer O. Johnson, University of Minnesota.
(The Scientific Monthly, v. LXXII, n. 6, June 1951, p. 384)

Modern statistical design of experiments as well as statistical analysis of data is essential to experimentation and research. This idea is developed in some detail by the author in presenting the role, methods, and aims of statistics as a scientific method.

Analysis of variance is discussed and illustrated along with the philosophy of sampling theory and practice.

QUALITY CONTROL OF COTTON FIBERS, R. M. Ashner, P. O. M. Co., Industrial Consultant, Werner Textile Consultants.
(Textile Industries, August, 1951)

Better testing of raw cotton is recommended as a means of reducing the gap in cost between natural and man-made fibers. The details of a testing program, organization, and laboratory layout are discussed.

WHY A STATISTICIAN? Maynard S. Renner, Asst. Research Director, Dewey & Almy Chemical Co., Cambridge, Mass.
(Tappi, v. 34, n. 7, July 1951, p. 92A)

A pertinent discussion of the need for statistical methods in planning experiments and for analyzing data. Points out the savings in time and cost when experiments are properly planned.

MANAGEMENT & PERSONNEL

AIR FORCE QUALITY CONTROL REQUIREMENTS, Major O. C. Griffith, Jr., Quality Control Division, Directorate of Procurement and Industrial Planning, Air Materiel Command.
(Technical Data Digest, v. 16, n. 7, July 1951, p. 19)

The USAF quality control acceptance requirements are based largely upon the contractor's maintenance of a production, inspection, and quality control system that will produce and insure the quality desired. Complete product inspection is then not necessary. Surveillance over the contractor's system, and limited inspection of items to verify the results of the system are used. The reasons for, and the philosophy of, this approach to military procurement are developed in this article.

The October, 1951, issue of "Tooling and Production" (page 82) also has this article.

FOUR STEPS IN MAINTAINING BETTER QUALITY, Ralph B. Bryan.
(Machine & Tool Blue Book, v. 47, n. 8, August 1951, p. 255)

Quality standards, basically a question of management decision, must be understood by all who have contact with the factors of control of quality. Cooperation and understanding between supervision in the various departments as well as with the workers is essential.

MISCELLANEOUS

4TH ANNUAL QUALITY CONTROL FEATURE ISSUE.
(Tooling & Production, v. XVII, n. 7, Oct. 1951)

This issue contains a series of articles on industrial appreciation of Quality Control.
These include:
"BEARING DOWN ON QUALITY", A. V. Toth, Cleveland Graphite Bronze Co.
"FORD INDICATES THE WAY TO QUALITY", Roscoe M. Smith, Ford Motor Co.
"PROFITABLE EXPERIENCE IN QUALITY CONTROL", Leo Harrington, King-Seeley Corp.
"GEARS OF EXCEPTIONAL QUALITY", H. S. Gist, Nash Motors.
"CONTROLLING PRECISION GRINDING", R. E. Penney, New York Air Brake Co.
"WHO IS RESPONSIBLE FOR PRODUCT QUALITY?" Joseph Manuele, Westinghouse Electric Corp.
"AIR FORCE QUALITY CONTROL REQUIREMENTS", Lt. Col. O. C. Griffith, Jr.
"THOMPSON TRAINING PROGRAM IN QUALITY CONTROL", James V. Strela.

MILITARY EMPHASIS AT QUALITY CONTROL CONVENTION, H. H. Roberts.
(Automotive Industries, v. 104,

n. 12, June 15, 1951, p. 52)

This is a report of the Fifth National Convention of the ASQC at Cleveland, May 1951. In addition to a review of some of the convention activities, extracts are given of three papers that were presented during the technical sessions.

Those are:

"QUALITY CONTROL ELIMINATES UNNECESSARY OPERATIONS", Roscoe C. Byers, Westinghouse Electric Corp.

"QUALITY CONTROL IN PARTS MANUFACTURING", E. F. Gibian, Thompson Products, Inc.

"PEOPLE, PISTON RINGS, AND QUALITY CONTROL," Carl E. Hoover, Perfect Circle Corp.

MODEL DEMONSTRATOR SHOWS VALUE OF QUALITY CONTROL CHARTS.
(Steel Equipment & Maintenance News, May 1951, p. 14)

Visual aid combats "I don't need high-powered mathematics to run my department" attitude by comparing probability against quality control charts. The quality control demonstrator is patterned basically after an old museum and university curiosity known as the "Statistical Quincunx", invented by Sir Francis Galton in the latter part of the 19th century. ("Quincunx", derived from Latin meaning "five ounce".)

STATISTICS

ON UNIFORMLY CONSISTENT TESTS, A. Berger.
(Annals of Mathematical Statistics, v. 22, June 1951, p. 289)

RELATIONS BETWEEN MOMENTS OF ORDER STATISTICS, R. H. Cole.
(Annals of Mathematical Statistics, v. 22, June 1951, p. 308)

SOME OBSERVATIONS ON THE PRACTICAL ASPECTS OF WEIGHING DESIGNS, K. S. Banerjee.
(Biometrika, v. 38, June 1951, p. 248)

USE OF SYSTEMATIC 5 X 5 SQUARES, O. Nissen.
(Biometrics, v. 38, June 1951, p. 167)

TWO METHODS OF RANDOMIZATION IN STATISTICS AND THE THEORY OF GAMES, A. Wald & J. Wolfowitz.
(Annals of Mathematics, v. 53, May 1951, p. 581)

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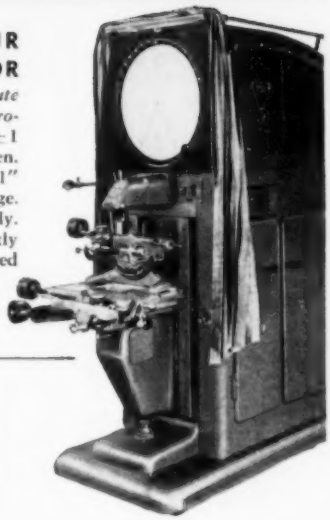
1 CONTOUR MEASURING PROJECTOR

Save time and money—*more accurate measurements than with any other projector!* Angular measurements to ±1 minute of arc, with protractor screen. Direct linear measurements to ±.0001" over 4" x 6" range, with cross slide stage. Spot inaccuracies quickly and simply. Compare production-run parts directly with a *traced outline* of the projected image of the master part, or with a large scale drawing superimposed on the screen. *Catalog* D-27.



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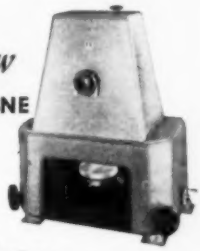

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WRITE for full information on these four important optical aids, to help you save time and money. You may be paying many times over their cost in lost time and rejects. Bausch & Lomb Optical Co., 795-13 St. Paul St., Rochester 2, N. Y.

Bausch & Lomb *Quality Control* Instruments

FROM THE SCRAP-BOX

Mr. J. Dunlap McNair (Muncie Section), of the Indiana Steel and Wire Company, submits the following contribution which he suggests appear as a Letter to the Editor, "thus putting the opprobrium on the character who wrote it, rather than giving it full status as a Society pronouncement."

Did you ever know a man who could not pronounce his own name? Probably not.

Did you ever know a man who could not pronounce his own business or profession? Probably so if you know very many people engaged in Statistical Quality Control. The word Statistics and its derivatives cause many twisted tongues.

Statistical Quality Control is an unfortunate title for a profession. No advertising man would have permitted such a name to have been used, because of the difficulty of saying it correctly.

Shortening the term to Quality Control leaves much to be desired. It asks for the uninformed answer, "Quality Control—sure, we have controlled quality for forty years".

Until some better name, fully descriptive and more easily pronounced, is accepted, the full name is to be preferred.

The crying need, then, is for correct pronunciation of Statistical (and Statistics and Statistician).

Careful visual inspection of the syllables should prove that any normal tongue can produce the word. Just watch where the "S" sounds belong and keep them there.

It is entirely probable that many of those who say "stastistics" do not realize it, so it might be instructive for everyone using the word to look at it with a skeptical eye to be sure that he is giving it only its allotted number of "s" sounds.

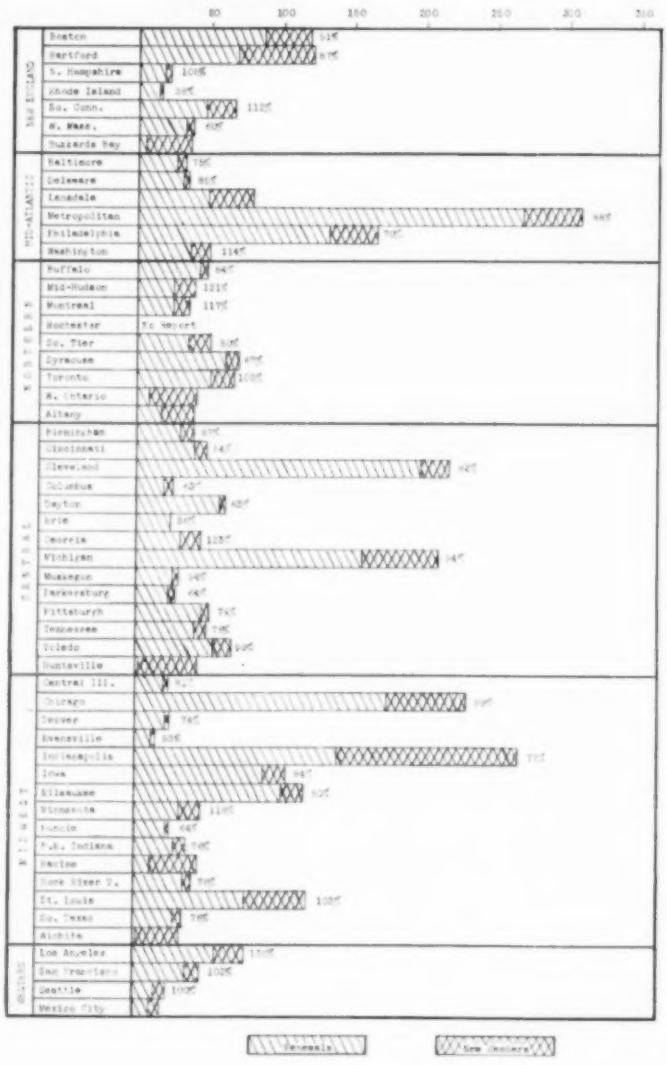
It is unfortunate that not one speaker but several in any ASQC program or conference should fall into this error, while the movement is struggling to become a profession.

While we are on our soap-box, two other terms come to mind that should be more carefully managed. One is "data", on which all our fine statistical methods are put to use. It is not "datta", it never was, and God and Webster willing, it never shall be. It is "date-a". Check it for yourself or take our word for it.

Lastly, and here some argument will probably arise, let's standardize how we read or say $\bar{X}$: X-Bar or Bar-X.

BAR CHART OF ASQC MEMBERSHIP BY SECTIONS AS OF OCTOBER 30, 1951, WITH PERCENTAGES SHOWING COMPARISON TO JUNE 30, 1951.

(Does not include Members-at-Large or In-Training)



MEMBERSHIP

Total membership as of October 30, 1951 was 3875, or 91% of last year's total. We have added 1035 new members since June 30. Only 67% of our old members had paid their dues before October 30. Membership Committees in the Sections *can* reduce delinquency by organizing to make personal contacts in advance of the deadline. Plan your work, then work your plan.

Robert S. Inglis, *Chairman*
Committee on Membership

Without any statistical data to confirm it, we would say the majority prefer X-Bar, although there is a considerable minority of Bar-X.

We say X-squared, X-prime, X-sub-1, X to the nth power. Why should we suddenly switch to the name of a ranch in a Grade B western movie, the Bar-X?

But let's everyone agree to go along. Terminology is no place to let individuality creep in. Everyone calculates it by the same, or mathematically equivalent, methods. Why not all call it the same?

And please don't say this sounds academic and pedantic. Professional stature for the practitioners of a new field of science will be harder to attain, the longer the terminology is either incorrect or not standardized.

FILM REVIEW—*"Quality Control by Statistical Methods MN6621A and B". Department of Defense, 16 mm Sound. Prints Available U. S. Office of Education. Review by Professor John A. Henry, University of Illinois.*

This is a two-reel presentation of statistical quality control prepared for the training of Navy procurement personnel, each reel being approximately 17 minutes in length. They are rather elementary in nature, with some application of the chart for measurements and acceptance sampling, but with little basic theory. They would be suitable for an introduction to in-plant training programs and extension courses, and to a promotional type of sectional meeting of the ASQC.

MN6621A—PROCESS QUALITY CONTROL deals almost entirely with the chart for measurements, with a little on the normal distribution and a flash of the fraction defective chart with no explanation. This film stresses the importance of corrective action on out-of-control points. It deals in generalities on such topics as the relation of specifications to control limits, modified limits, and stratified sampling. No attempt is made to discuss the relationship between individual readings and averages of samples.

MN6621B—ACCEPTANCE SAMPLING is in general a better film, reflecting the interest of the armed forces in procurement. It starts with a brief review of process control and discusses the economic realities of acceptance, rejection, and screening of lots. A good case is made for careful inspection of a sample as com-

MEASURE IN MICROINCHES RMS

What Does Belong— *in this Picture?*

...*the* PROFILOMETER *at the* NORTON SCHOOL OF GRINDING

Shown above is a customer group attending the school of grinding of the Norton Company, Worcester, Massachusetts. Here the latest grinding machine developments are explained to representatives of a number of the country's leading industrial firms.

One piece of equipment appears in this picture... the Profilometer. Obviously, in a discussion of modern grinding techniques, an accurate knowledge of the surface finishes that are secured is of primary importance. Norton Company recognizes the Profilometer as the instrument which does provide dependable roughness ratings in microinches RMS—the accepted standard of measurement throughout industry. For that reason, the Profilometer *does* belong in this picture—and on this conference table.

To the men who attend these sessions, the value of the Profilometer increases immeasurably when they put it to everyday use in the production departments of their own plants. There it becomes a part of routine grinding and other machining procedure . . . a means to secure exactly, quickly and easily the information desired on surface finishes. That is why you find it "in the picture" in their companies and wherever quality control is a consideration.

To learn how the Profilometer can help cut costs in your production, write today for these free bulletins.

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pared with superficial 100 percent inspection. Classification of defects is presented, and mention made of acceptable quality levels. The MIL-STD-105A tables are specifically referred to, but some shots are made of the JAN-105 tables. The operating characteristic curve is shown, but not explained. Multiple sampling is rather cleverly presented, and the film closes with an effective skit on vendor-purchaser relations. The AQQL concept is not mentioned, but acceptance by variables is.

HOW EFFECTIVE IS 100% INSPECTION?

Contributed as an item used on the program of the Indianapolis Section at its "Kick-Off Meeting", September 18, 1951.

Industry has been laboring under the impression that 100% inspection gives complete assurance that lots submitted for inspection will be effectively sorted.

Herewith are 450 random three digit numbers. Assume that numbers in the range 851 through 900 inclusive are defectives. Go through this "lot" once only and see how effectively you can sort out the defectives by check-marking each one you find. Allow a maximum of three minutes to complete the inspection and get the total number of defectives you found. Compare your total with the correct answer on page 50.

921	250	401	976	121	931	084	435	980	428
335	142	212	842	282	741	402	418	924	039
867	499	018	496	589	317	233	381	802	534
612	066	927	222	975	211	952	217	027	398
348	893	048	826	241	306	031	430	511	286
763	952	862	501	877	996	868	497	892	057
726	240	548	655	566	285	818	168	339	336
163	824	321	659	840	869	749	481	071	519
830	005	048	960	745	405	000	941	357	655
836	903	857	701	436	065	589	010	329	548
669	694	623	459	203	856	420	896	285	588
808	944	999	972	868	685	424	087	676	190
631	000	298	526	684	774	797	753	643	469
230	928	563	137	649	101	494	828	103	322
483	588	637	632	572	459	293	074	803	481
108	685	213	691	120	502	835	122	362	556
704	807	865	878	848	775	658	499	298	055
770	445	079	672	226	741	216	653	051	411
734	019	267	479	654	794	897	965	998	997
960	890	786	648	477	272	035	766	464	131
765	369	941	482	992	472	922	342	732	093
424	726	000	245	462	650	811	944	049	127
178	202	199	170	115	033	926	792	634	449
240	006	747	463	154	822	465	084	680	251
800	325	827	305	761	195	605	994	360	704
026	326	604	861	097	311	504	677	828	959
069	158	228	277	306	315	304	277	224	154
065	957	830	684	519	335	133	912	672	414
138	844	532	202	854	489	160	705	287	852
400	930	444	940	420	883	330	759	173	570
951	315	664	997	313	614	899	169	423	661
884	092	285	462	624	771	904	021	124	212
285	344	389	419	434	436	423	396	356	301
232	150	053	943	820	683	532	368	191	796
579	349	160	850	581	299	004	697	377	044
699	341	971	588	194	787	367	936	492	037
569	090	599	096	581	054	516	966	405	832
248	652	045	427	797	156	505	842	167	482
786	079	362	633	894	144	383	611	829	037
234	420	597	762	918	063	198	323	437	542
636	721	795	860	914	959	994	019	034	040
036	022	999	966	924	872	811	741	661	572
473	365	248	122	987	842	689	526	355	174
985	787	579	363	139	905	663	412	152	884
607	321	027	725	414	094	766	430	086	733

AMERICAN SOCIETY NEWS

ASQC NOW AN AFFILIATED SOCIETY OF AAAS

In August, 1950, the American Society for Quality Control was invited to consider the desirability of joining the American Association for the Advancement of Science (AAAS) as an Affiliated Society. After due consideration of this invitation by the Executive Committee and some exchange of correspondence involving matters of information of mutual interest to both ASQC and AAAS, arrangements were completed providing the status of Affiliated Society in AAAS to ASQC.

AAAS was organized in 1848, incorporated in 1874, and is the oldest general national scientific society on this continent. Purposes for which it was established are:

To further the work of scientists.
To facilitate cooperation among scientists.
To improve the effectiveness of science in the promotion of human welfare.
To increase public understanding and appreciation of the importance and promise of the methods of science in human progress.

As an Affiliated Society of AAAS, ASQC assumes no obligations other than lending its name in support of the above objectives. Among societies appearing as Affiliated Societies of AAAS, members of ASQC will recognize the American Ceramics Society, the American Institute of Electrical Engineers, the American Society for Engineering Education, the American Society for Testing Materials, the American Society of Mechanical Engineers, the Institute of Radio Engineers, the American Statistical Association, and the Institute of Mathematical Statistics, to mention a few.

Miss Besse B. Day, Director for the Middle Atlantic Region, ASQC, and a Fellow of AAAS, has been appointed as the Society's official representative on the AAAS Council. Because of the broad coverage of fields of interest in ASQC and the fact that at present there is no Section of AAAS specifically encompassing our field, the Society is requesting assignment to the Engineering Section.

The American Society for Quality Control is proud to have joined hands with its fellow professional engineering and scientific societies in the capacity of an Affiliated Society of the American Association for the Advancement of Science.

NEW SECTION IN ALBANY

The Society wishes to extend a warm welcome to all the members of the Albany Section, which was admitted on November 17, 1951, as the fifty-fourth Section of the Society. Officers of this Section are as follows:

National Director, F. E. Satterthwaite, General Electric Co.
Chairman, Edward L. Bauer, Winthrop-Stearns, Inc.
Vice Chairman, R. R. Jones, Bigelow-Sanford Carpet Co.
Secretary, J. L. Dolby, General Electric Co.
Treasurer, Hyman Stein, Star Woolen Co.

In accordance with the request of this group the Section has been assigned to the New England Region.

1955 NATIONAL CONVENTION

Specific arrangements have been made in connection with the Ninth ASQC Convention in New York City. Headquarters will be the Statler Hotel, and the dates will be May 23-26, inclusive, 1955.

EXECUTIVE COMMITTEE MEETS

The Executive Committee of the Society held meetings at the Hotel Sherman, Chicago, on November 17 and 18, 1951. Important highlights from the meeting are listed below.

The report of the Executive Secretary on membership status as of November 15, 1951, showed a total of 4,275 members compared to 4,245 as of June 30, 1951. Of this total number, 3,094 are renewing members—73% of last year's total, and 1,181 are new members. Such extremely rapid growth imposes not only many physical problems of keeping abreast of things in our National Office, but also difficult problems of an organizational and planning nature upon the Society executives.

The report of the Treasurer for the period of July 1-November 15, 1951, showed that with 37½% of the fiscal year behind us, total income amounted to 76% of the amount budgeted for the entire year, while expenses amounted to 36% of the annual budget.

The Vice President held a concurrent meeting with the Chairmen of the Society General Committees and the Special Assistant to the President on Technical Committee Coordination. This meeting laid the groundwork for special programs of our various committees, programs which will be instituted at once, as

PUBLICATIONS AVAILABLE

"Quality Control Conference Papers"—Fifth Annual ASQC Convention—38 Papers ..... $3.50 per copy

"Proceedings"—Middle Atlantic Regional Conference, 1951—16 Papers ..... $2.50 per copy

ASTM Manual on Quality Control of Materials (Revised Edition). Available to ASQC Members .. $1.50 per copy

Hamilton Standard Lot Plot Plan—a reprint 50¢ per copy

Make remittance payable to: American Society for Quality Control. Order from: Alfred L. Davis, 65 Plymouth Ave., South, Rochester 8, N. Y.

REQUEST TO AUTOMOTIVE INDUSTRIES

The Automotive Technical Committee, ASQC, is maneuvering into a position where it can be of service to the automotive industry by handling requests for technical literature on quality control applied in the automotive field. Building an adequate file of case histories is a big project. We are, therefore, requesting automotive manufacturers and their suppliers to contribute as many case histories as possible.

Please send all literature to:
W. H. Coughlin, Thompson Products, Inc.
23555 Euclid Ave., Cleveland 17, Ohio

well as some long range planning for Society activities.

Last year the membership registered "approval of intent" that the Society should have more than one Vice President, the exact number to be at the discretion of the Board of Directors. The Constitution and By-Laws Committee has drafted the changes necessary in our Constitution to implement this mandate, and these were carefully reviewed and approved by the Executive Committee. Three other By-Laws recommended by the Constitution and By-Laws Committee were similarly reviewed and approved. All these now go to the Board of Directors for their review and, if endorsed by that Board, the items requiring Constitutional changes will be presented to the Membership for ratification at the time of the 1952 balloting for officers.

As our Society continues to grow larger and gain more experience, it naturally tends to outgrow certain phases of its Constitution. Modernizing changes will constantly be in order for a Constitution which was drafted to govern a much smaller Society.

Answer for page 48: 25.

POSITIONS AVAILABLE

Address all replies to box number references to: American Society for Quality Control, Room 5036, 70 East 45th Street, New York 17, N.Y.

QUALITY CONTROL ENGINEER-Graduate E.E., M.E., or ChE. experienced in setting-up quality control systems for products in pilot-plant, pre-production and production stages. Knowledge of SQC essential. Medium sized manufacturing company, eastern location. Please reply to 8K1 at above address.

CONSULTING SERVICES

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New! GE

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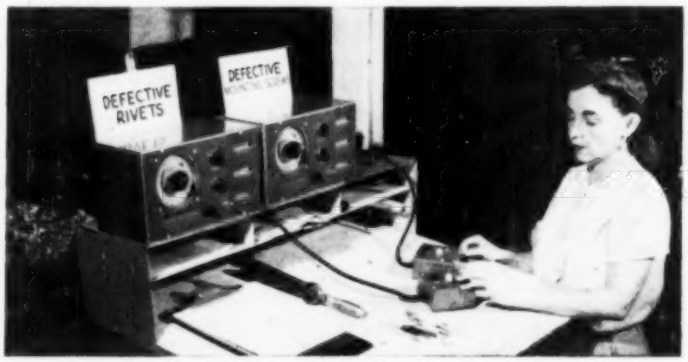

G-E Continuous Sampling Monitor used in plant of large eastern appliance manufacturer.

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Now you can keep track of complex inspection techniques with the Continuous Sampling Monitor . . . newest addition to the General Electric line of instruments developed to improve your quality control program.

By recording units accepted and rejected, the Continuous Sampling Monitor informs the inspector whether periodic sampling, or 100% inspection is required.

The AOQL (average outgoing quality limit) is thus insured by maintaining correct inspection techniques.

- **Ends "paperwork" by inspectors**
- **Reduces inspection time**

Look into the advantages of a Continuous Sampling Monitor. Try one on your production line and see how your quality control improves!

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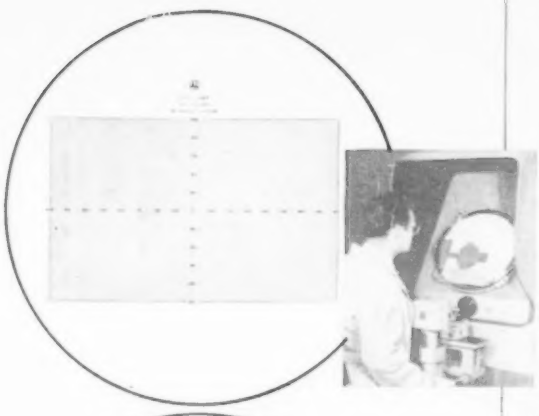

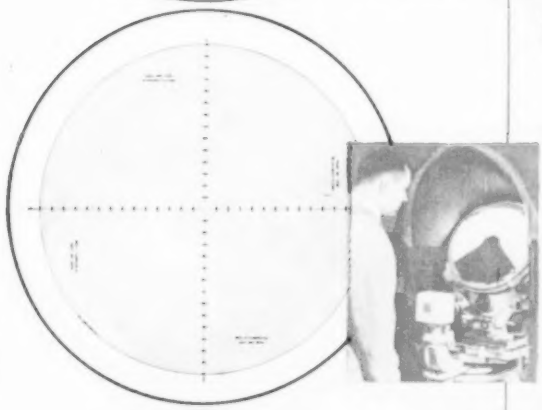

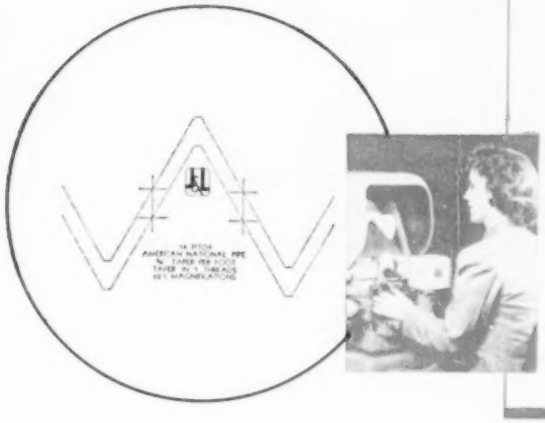

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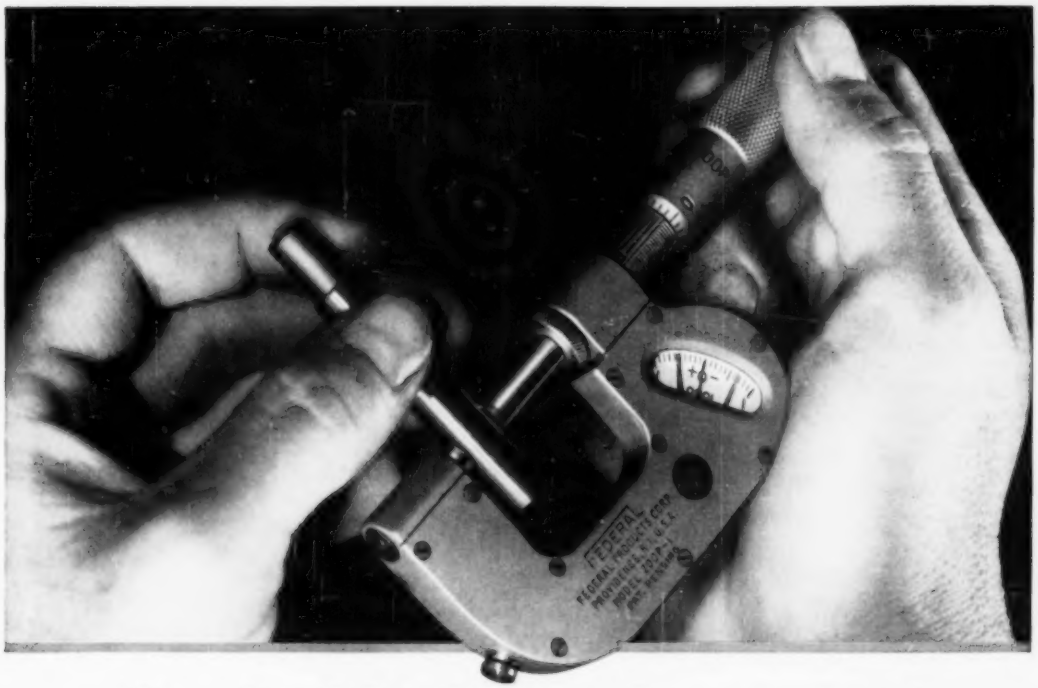
Springfield, Vermont, U.S.A.

MACHINE TOOL CRAFTSMEN SINCE 1835



the double-duty micrometer!

You're in for a real surprise the first time you use a Federal MIKEMASTER! You'll be amazed at the honest-to-goodness convenience and downright accuracy of this *indicating micrometer*. You'll like its double-usefulness, too — the way you can use it as an *indicating snap gage* for measuring duplicate parts.

Actual test proves the MIKEMASTER eliminates errors of "feel":

Four people, using a high grade conventional micrometer, measured the same diameter on the same piece three times. All measurements differed from .0002" to .0008". Only one measurement was correct. With the Mikemaster in a similar test, *all measurements but one* were exactly "on the nose" and this one showed less than .0001" variation.

Here are the *big* features that make this tool far superior to regular old-style "mikes":

- **BUILT-IN DIAL INDICATOR** with clear graduations and easy-to-set Tolerance Hands for quick size checking down to a .0001".
- **CONSTANT ANVIL PRESSURE** that eliminates errors of "feel" . . . insures the same high accuracy no matter who is measuring with the Mikemaster.
- **RETRACTABLE LOWER ANVIL** for easy (non-scratching) insertion of workpieces when checking duplicate parts or inspecting for taper and roundness.

You have to handle the Mikemaster yourself to fully appreciate what it can do for you. *Write for a free demonstration.* FEDERAL PRODUCTS CORPORATION, 1151 Eddy Street, Providence 1, Rhode Island.

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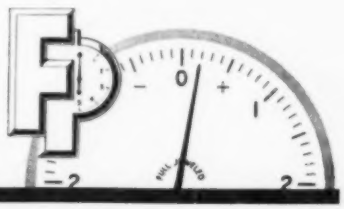
Largest manufacturer devoted exclusively to designing and manufacturing *all types* of DIMENSIONAL INDICATING GAGES